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ABSTRACT

These materials have been designed for use with the upper elementary through high school levels especially, but not exclusively, with the Lunar Sample Disk. This book contains: information on the Lunar Sample Disk, a curriculum content matrix, a teacher's guide, Moon ABCs fact sheet, rock ABCs fact sheet, Progress in Lunar Science chart, 17 activities, a resource section for each unit, and a list of National Aeronautics and Space Administration (NASA) educational resources. The activities are divided into three units: pre-Apollo, learning from Apollo, and the future. Classroom activities included promote problem-solving, communication skills, and teamwork. Each activity consists of teacher pages and reproducible student sheets. Teacher pages include a statement of purpose, background information, preparation, in-class suggestions, wrap-up ideas, and extensions. Student sheets include a purpose statement, key words, list of materials, procedure, questions with space provided for answers, and charts. Activities include: distance to the Moon, diameter of the Moon, reaping rocks, Apollo landing sites, Regolith formation, lunar surface, differentiation, impact craters, clay lava flows, lava layering, lunar landing sites, lunar roving vehicle, moon anomalies, lunar land use, life support systems, and lunar biospheres. (JRH)

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EXPLORING THE MOON

a Teacher's Guide with activities for Earth and Space Sciences

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EXPLORING THE MOON

a Teacher's Guide with activities for Earth and Space Sciences

National Aeronautics and Space Administration

Office of Human Resources and Education
Education Division

Office of Space Science
Solar System Exploration Division

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EP-306 September 1994

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About the cover

Our knowledge and concepts of the Moon change over time as depicted by the three images.
A map of the Moon (circa 1700s) is overlaid by an Apollo 11 astronaut footprint (NASA photo AS11-40-5878) and a NASA painting of a future lunar habitation module by Pat Rawlings of Science Applications International Corporation.

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4

Table of Contents

About This Book iii
About the Lunar Sample Disk iv
About the Slide Set v
Curriculum Content Matrix vi

Teacher's Guide The Moon: Gateway to the Solar System 1
Moon ABCs Fact Sheet 17
Rock ABCs Fact Sheet 19
Progress in Lunar Science Chart 20
Nearside of the Moon Photo--Apollo Landing Sites 21

Unit 1 Pre-Apollo 23
Resource Section for Unit 1 24
Distance to the Moon 25
Diameter of the Moon 29
Reaping Rocks 33

Unit 2 Learning From Apollo 37
Resource Section for Unit 2 38
The Lunar Disk 39
Apollo Landing Sites 43
Regolith Formation 47
Lunar Surface 53
Differentiation 57
Impact Craters 61
Clay Lava Flows 71
Lava Layering 77
Lunar Landing Sites 83
Lunar Roving Vehicle 87
Moon Anomalies 91

Unit 3 The Future 99
Resource Section for Unit 3 100
Lunar Land Use 101
Life Support Systems 109
Lunar Biospheres 129

Glossary 141
NASA Educational Resources 145

About this Book

These materials have been designed for use in upper elementary through high schools especially, but not exclusively, with the Lunar Sample Disk. See Page iv.

This book contains:
- information on the Lunar Sample Disk,
- a Curriculum Content Matrix,
- a Teacher's Guide,
- Moon ABCs Fact Sheet,
- Rock ABCs Fact Sheet,
- Progress in Lunar Science Chart,
- 17 activities,
- Resource Section for each unit,
- Glossary,
- NASA Educational Resources.

The "Teacher's Guide" titled "The Moon: Gateway to the Solar System," pages 1-16, provides background information about the Moon. It tells the story of the Moon's geological history and how scientists try to decipher the story. This background information may be useful reading for students as well. Key facts about the Moon appear on the "Moon ABCs" and "Rock ABCs" pages. These pages were named to emphasize the basic nature of the information. The "Progress in Lunar Science Chart" summarizes our knowledge about the Moon from 1959 to 1994.

The activities are divided into three units: Pre-Apollo, Learning from Apollo, and the Future. These correspond, at least roughly, to exercises that can be done before the Lunar Sample Disk arrives at your school (Pre-Apollo), while it is there (Learning from Apollo), and after it has been returned to NASA (The Future).

The length of time needed to complete an activity will vary according to the degree of difficulty and the development level of the students. Thus activities may take one to eight or more class periods.

A "Curriculum Content Matrix" is provided to assist in identifying the learning experiences of each activity.

Classroom activities promote problem-solving, communication skills, and teamwork. Each activity consists of teacher pages and reproducible student sheets.

Teacher pages begin with a statement of purpose and background information with answers specific to the activity. Relevant pages in the "Teacher's Guide" also are listed. These are followed by sections on preparation, in-class suggestions, wrap-up ideas, and extensions. Words that are bolded appear in the Glossary.

Student sheets include a purpose statement, key words, list of materials, procedure, questions with space provided for answers, and charts. Key words are included in the Glossary. Materials for each activity are listed in order of use. They are bolded in the text of the procedure section as a memory aid for students.

A note on measurements: These activities use metric units of measure with the few exceptions when English units are used to describe items from the material lists such as pans or measuring cups.

About the Lunar Sample Disk

Legacy of Apollo

The collection of rocks and regolith from the Moon is a tangible legacy of the U.S. Apollo Space Program. NASA makes a small portion of this "extraterrestrial" material available for classroom use through the Lunar Sample Loan Program.

Lunar Sample Loan Program

Six samples of rocks and regolith are embedded in a 15-cm diameter plastic disk. Disks are sent via registered mail to educators for one- to two-week loan periods. The package also includes this book *Exploring the Moon*, an annotated slide set of lunar images (described more fully on Page v), and a collection of color photographs and descriptions of the six samples.

How to Schedule a Disk

Educators must first be certified to borrow lunar material by attending a training seminar on security requirements and proper handling of the disk. Then a written request must be sent to a NASA Center Education Program Office at least one month prior to the requested loan date.

Contact the Center Education Program Office that serves your geographic area for more information on certification seminars and request procedures. A list of offices appears on Pages 147 and 148.

Ninth grade science students from Waipahu High School, Hawai'i view the Lunar Sample Disk as part of an activity from *Exploring the Moon*.

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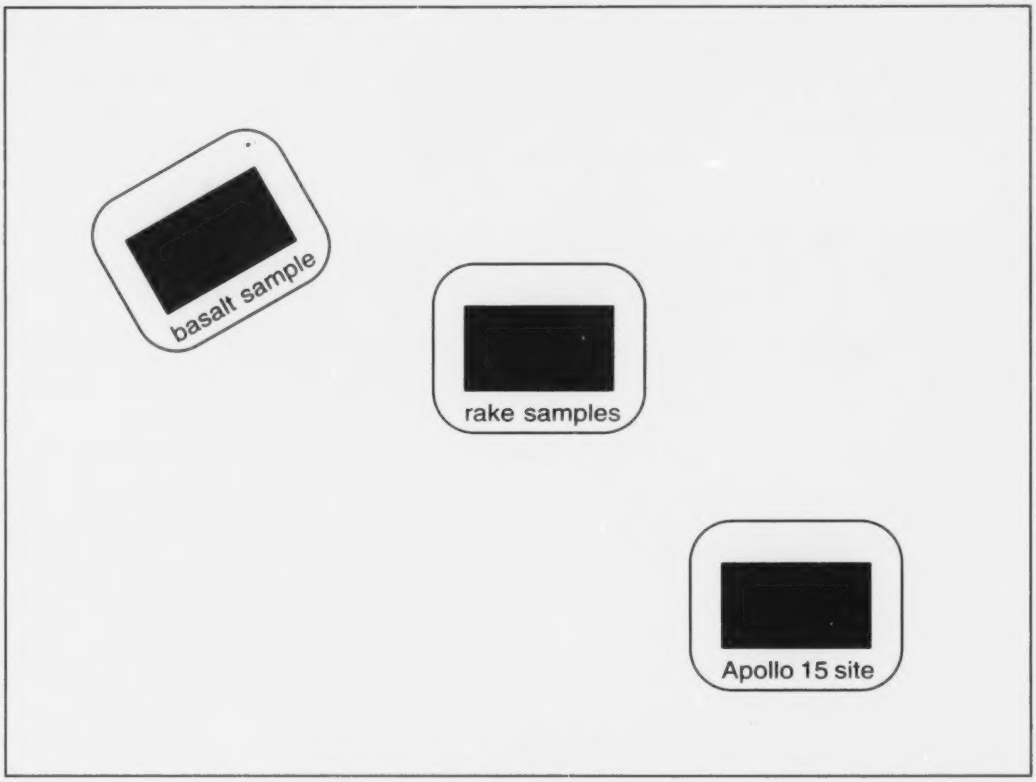
About the Slide Set

The Collection

A set of thirty-six 35-mm slides has been assembled to complement the activities in this book *Exploring the Moon.* Each slide is accompanied by detailed captions. Topics include what we knew about the Moon from telescopic and other astronomic observations before Apollo, Apollo missions, astronaut activities on the lunar surface, the Highlands, the Maria, how the Moon formed, and exciting ideas for future explorations.

How to Obtain a Copy

It is easy to obtain a copy of the slides. They are available from the Central Operation of Resources for Educators (CORE) in Ohio or from NASA Teacher Resource Centers. Phone calls are welcome if you are unable to visit the Teacher Resource Center that serves your geographic area. Please refer to Pages 145 - 148 in this book for addresses and phone numbers for CORE and Teacher Resource Centers.



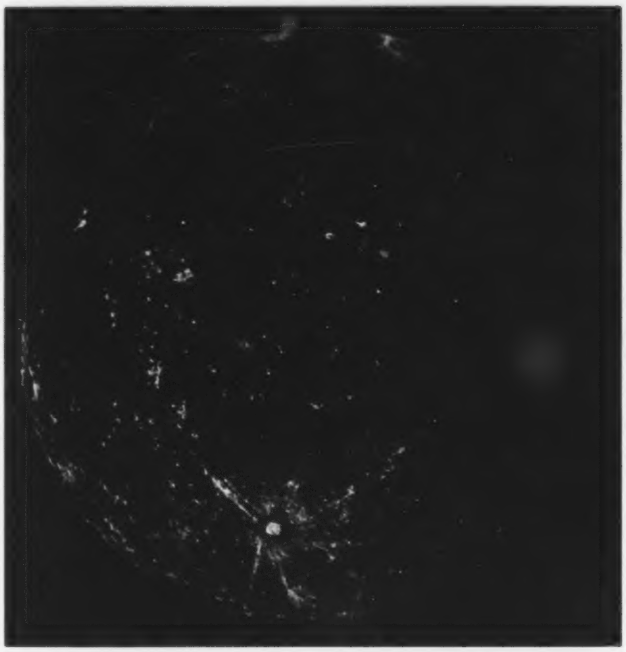
Curriculum Content Matrix

		Page	Observing	Classifying	Drawing	Physical Modeling	Measuring	Organizing Data	Interpreting Data	Inferring	Predicting	Decision Making	Controlling Variables	Formulating Hypotheses	Debating
Distance to the Moon	**Unit 1**	25	●		●		●	●	●						
Diameter of the Moon	Pre-Apollo	29	●				●	●	●						
Reaping Rocks		33	●	●	●		●	●	●		●	●			
The Lunar Disk	**Unit 2**	39	●	●	●		●	●	●		●	●			
Apollo Landing Sites		43	●					●	●						
Regolith Formation		47	●			●				●	●		●		
Lunar Surface		53	●	●		●			●	●					
Differentiation	Learning From Apollo	57	●	●		●			●		●				
Impact Craters		61	●			●	●	●	●	●			●	●	
Clay Lava Flows		71	●		●	●	●	●	●				●		
Lava Layering		77	●		●	●				●					
Lunar Landing Sites		83	●		●	●				●		●			●
Lunar Roving Vehicle		87	●		●	●						●	●		
Moon Anomalies		91								●		●		●	●
Lunar Land Use	**Unit 3**	101			●	●				●		●		●	●
Life Support Systems	Future	109	●	●	●	●	●	●	●	●	●	●	●	●	●
Lunar Biosphere		129	●	●	●	●	●	●	●	●	●	●	●	●	●

Adapted from Virginia Department of Education Science Textbook Evaluation Instrument.

THE MOON
GATEWAY TO THE SOLAR SYSTEM

G. Jeffrey Taylor, PhD



WHEN ASTRONAUTS dug into the Moon's surface during the Apollo program, they were doing more than digging up dry, dark sediment. They were time travelers. The rocks and sediment returned by Apollo contain vital clues to how Earth and the Moon formed, the nature and timing of early melting, the intensity of impact bombardment and its variation with time, and even the history of the Sun. Most of this information, crucial parts of the story of planet Earth, cannot be learned by studying rocks on Earth because our planet is so geologically active that it has erased much of the record. The clues have been lost in billions of years of mountain building, volcanism, weathering, and erosion. Colliding tectonic plates

The Moon, front and back

The **top right** photograph is a telescopic image of the Earth-facing half of the Moon obtained at Lick Observatory in California. The one **below right** was taken during the Apollo 16 mission and shows mostly the farside, except for the dark areas on the left, which can be seen, though barely, from Earth. The two major types of terrain are clearly visible. The *highlands*, which are especially well displayed in the photograph of the farside, are light-colored and heavily cratered. The *maria* are darker and smoother; they formed when lava flows filled depressions. One of the mysteries about the Moon is why fewer maria occur on the farside than nearside. Note how many craters stand shoulder to shoulder on the farside. These immense holes chronicle the Moon's early bombardment, an intense barrage that probably affected the early Earth as well.

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and falling rain are erasing much of Earth history, especially the early years before four billion years ago.

The Moon was geologically active in its heyday, producing a fascinating array of products, but its geologic engine was not vigorous and all records of early events were not lost. Its secrets are recorded in its craters, plains, and rocks. This guide reveals the secrets that lunar scientists have uncovered since the Apollo missions returned 382 kilograms (843 pounds) of rock and sediment from the lovely body that graces the night sky.

The emphasis here is on geology. The samples returned by Apollo are the stars of the show. [*See the "Lunar Disk" activity on Pages 39–42 and the "Apollo Landing Sites" activity on Pages 43–46.*] Understanding the Moon, however, requires other geological approaches, such as geological mapping from high-quality photographs, the study of analogous features on Earth (for instance, impact craters), and experiments in laboratories.

THE LUNAR LANDSCAPE

The Moon is not like Earth. It does not have oceans, lakes, rivers, or streams. It does not have wind-blown ice fields at its poles. Roses and morning glories do not sprout from its charcoal gray, dusty surface. Redwoods do not tower above its cratered ground. Dinosaur foot prints cannot be found. Paramecium never conjugated, amoeba never split, and dogs never barked. The wind never blew. People never lived there—but they have wondered about it for centuries, and a few lucky ones have even visited it.

Highlands and lowlands

The major features of the Moon's surface can be seen by just looking up at it. It has lighter and darker areas. These distinctive terrains are the bright lunar highlands (also known as the *lunar terrae*, which is Latin for "land") and the darker plains called the *lunar maria*, Latin for "seas," which they resembled to Thomas Hariot and Galileo Galilei, the first scientists to examine the Moon with telescopes. The names *terrae* and *maria* were given to lunar terrains by Hariot and Galileo's contemporary, Johannes Kepler. In fact, the idea that the highlands and maria correspond to lands and seas appears to have been popular among ancient Greeks long before telescopes were invented. Although we now know they are not seas (the Moon never had any water), we still use the term *maria*, and its singular form, *mare*.

The highlands and craters

Closer inspection shows that the highlands comprise countless overlapping craters, ranging in size from the smallest visible in photographs (1 meter on the best Apollo photographs) to more than 1000 km. Essentially all of these craters formed when meteorites crashed into the Moon. Before either robotic or piloted spacecraft went to the Moon, many scientists thought that most lunar craters were volcanic in origin. But as we found out more about the nature of lunar craters and studied impact craters on Earth, it became clear that the Moon has been bombarded by cosmic projectiles. The samples returned by the Apollo missions confirmed the pervasive role impact processes play in shaping the lunar landscape.

The term "meteorite impact" is used to describe the process of surface bombardment by cosmic object. The objects themselves are variously referred to as "impactors" or "projectiles."

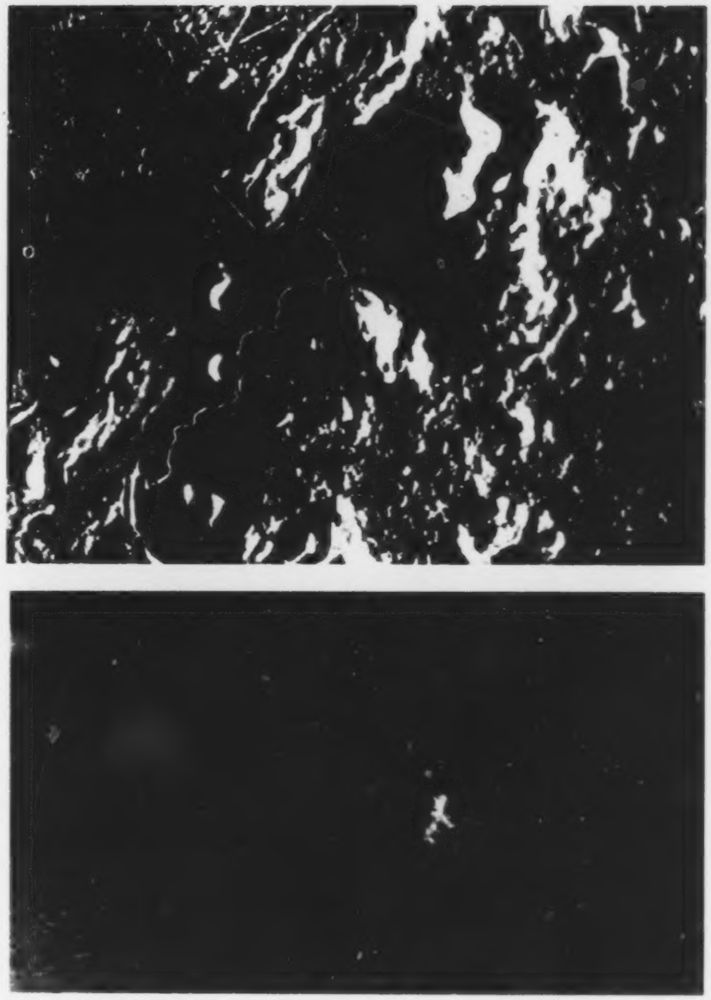
The impact process is explosive. A large impactor does not simply bore its way into a planet's surface. When it hits, it is moving extremely fast, more than 20 km/sec (70,000 km/hour). This meeting is not tender. High-pressure waves are sent back into the impactor and into the target planet. The impactor is so overwhelmed by the passage of the shock wave that almost all of it vaporizes, never to be seen again. The target material is compressed strongly, then decompressed. A little is vaporized, some melted, but most (a mass of about 10,000 times the mass of the impactor) is tossed out of the target area, piling up around the hole so produced. The bottom of the crater is lower than the original ground surface, the piled up material on the rim is higher. This is the characteristic shape of an impact crater and is different from volcanic calderas (no piled up materials) or cinder cones (the central pit is above the original ground surface). A small amount of the target is also tossed great distances along arcuate paths called *rays*.

Real impacts cannot be readily simulated in a classroom. In fact, there are very few facilities where we can simulate high-velocity impacts. Nevertheless, classroom experiments using marbles, ball bearings, or other objects can still illustrate many important points about the impact process. For example, objects impacting at a variety of velocities (hence kinetic energies) produce craters with a variety of sizes; the more energy, the larger the crater. [*See the "Impact Craters" activity on Pages 61–70.*]

The maria

The maria cover 16% of the lunar surface and are composed of lava flows that filled relatively low places, mostly inside immense impact basins. So, although the Moon does not have many volcanic craters, it did experience volcanic activity. Close examination of the relationships between the highlands and the maria shows that this activity took place after the highlands formed and after most of the cratering took place. Thus, the maria are younger than the highlands. [*See the "Clay Lava Flows" activity on Pages 71–76 and the "Lava Layering" activity on Pages 77–82.*]

How do we know that the dark plains are covered with lava flows? Why not some other kind of rock? Even before the Apollo missions brought back samples from the maria, there were strong suspicions that the plains were volcanic. They contain some features that look very much like lava flows. Other features resemble lava channels, which form in some types of lava flows on Earth. Still other features resemble collapses along underground volcanic features called lava tubes. These and other features convinced most lunar scientists before the Apollo missions that the maria were lava plains. This insight was confirmed by samples collected from the maria: they are a type of volcanic rock called *basalt.*



Rivers or lava channels?

The origin of river-like valleys, called rilles, was debated before the Apollo 15 mission visited one of them, Hadley Rille, shown here from orbit (white arrow shows the landing site) and from the lunar surface. Some scientists argued that rilles were river valleys, implying that the Moon had flowing water at one time. Others thought that rilles resembled the channels that form in lava flows. Observations by the Apollo 15 crew and samples returned settled the argument: rilles are volcanic features.

The maria fill many of the gigantic impact basins that decorate the Moon's nearside. (The Moon keeps the same hemisphere towards Earth because Earth's gravity has locked in the Moon's rotation.) Some scientists contended during the 1960s that this demonstrated a cause and effect: impact caused not only the formation of a large crater but led to melting of the lunar interior as well. Thus, it was argued, the impacts triggered the volcanism. However, careful geologic mapping using high-quality telescopic images, showed that the mare must be considerably younger than the basins in which they reside. For example, the impact that formed the large Imbrium basin (the Man-in-the-Moon's right eye) hurled material outwards and sculpted the mountains surrounding the Serenitatis basin (the left eye); thus, Serenitatis must be older. The Serenitatis basin is also home to Mare Serenitatis. If the lavas in Mare Serentatis formed when the basin did, they ought to show the effects of the giant impact that formed Imbrium. They show no

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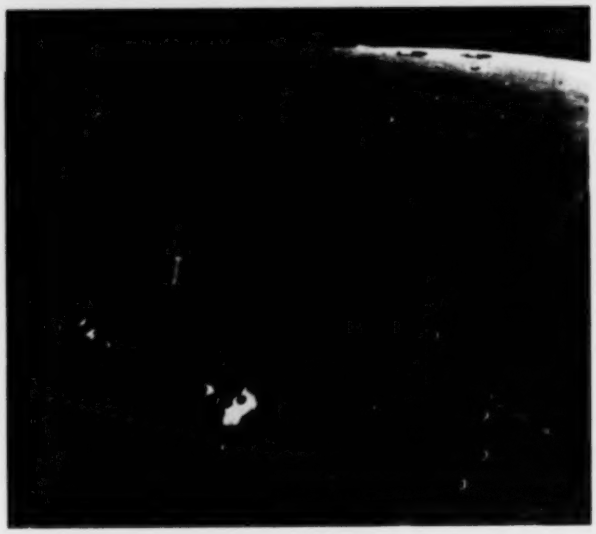

Lava flows dribbling across Mare Imbrium

Long lava flows (lower left to upper right through center of photo) in Mare Imbrium. The flows are up to 400 kilometers long (the entire extent is not shown in this Apollo photograph) and have 30-meter high cliffs at their margins. The ridges running roughly perpendicular to the flows are called wrinkle ridges. The ridges formed after the flows because they did not impede the advance of the lava flow. The smooth plains surrounding the prominent lava flows are also lava, but older, so the margins are harder to see. The craters on the right along the ridge are about 5 kilometers in diameter.

signs of it. Furthermore, the maria contain far fewer craters than do basin deposits, hence have been around a shorter time (the older the surface, the greater the number of craters). The Apollo samples, of course, confirmed these astute geological observations and showed that the maria filling some basins formed a billion years after the basin formed.

One other type of deposit associated with the maria, though it blankets highlands areas as well, is known as *dark mantle deposits*. They cannot be seen except with telescopes or from spacecraft near the Moon, but are important nonetheless. Before Apollo, most scientists believed that the dark mantle deposits were formed by explosive volcanic eruptions known as *pyroclastic eruptions* (literally, "pieces of fire"). Some deposits seemed to be associated with low, broad, dark cinder cones, consistent with the idea that they were formed by pyroclastic eruptions—this is how cinder cones form on Earth. This bit of geologic deduction was proven by the Apollo 17 mission and its sampling of the "orange soil," a collection of tiny glass droplets like those found in terrestrial pyroclastic eruptions.

Maria mysteries

Some mysteries persist about the maria. For one, why are volcanoes missing except for the cinder cones associated with dark mantle deposits? Second, if no obvious volcanoes exist, where did the lavas erupt from? In some cases, we can see that lava emerged from the margins of enormous impact basins, perhaps along cracks concentric to the basin. But in most cases, we cannot see the places where the lava erupted. Another curious feature is that almost all the maria occur on the Earth-facing side of the Moon. Most scientists guess that this asymmetry is caused by the highlands crust being thicker on the lunar farside, making it difficult for basalts to make it all the way through to the surface. [*See the "Moon Anomalies" activity on Pages 91–98.*]

THE DUSTY LUNAR SURFACE

Some visitors to Kilauea Volcano, Hawai'i, have been overheard to say, upon seeing a vast landscape covered with fresh lava, "It looks just like the Moon." Well, it doesn't. The fresh lava flows of Kilauea and other active volcanoes are usually dark grayish and barren like the Moon, but the resemblance ends there. The lunar surface is charcoal gray and sandy, with a sizable supply of fine sediment. Meteorite impacts over billions of years have ground up the formerly fresh surfaces into powder. Because the Moon has virtually no atmosphere, even the tiniest meteorite strikes a defenseless surface at its full cosmic velocity, at least 20 km/sec. Some rocks lie strewn about the surface, resembling boulders sticking up through fresh snow on the slopes of Aspen or Vail. Even these boulders won't last long, maybe a few hundred million years, before they are ground up into powder by the relentless rain of high-speed projectiles. Of course, an occasional larger impactor arrives, say the size of a car, and excavates fresh rock from beneath the blanket of powdery sediment. The meteoritic rain then begins to grind the fresh boulders down, slowly but inevitably.

The powdery blanket that covers the Moon is called the *lunar regolith*, a term for mechanically produced debris layers on planetary surfaces. Many scientists also call it the "lunar soil," but it contains none of the organic matter that occurs in soils on Earth. Some people use the term "sediment" for

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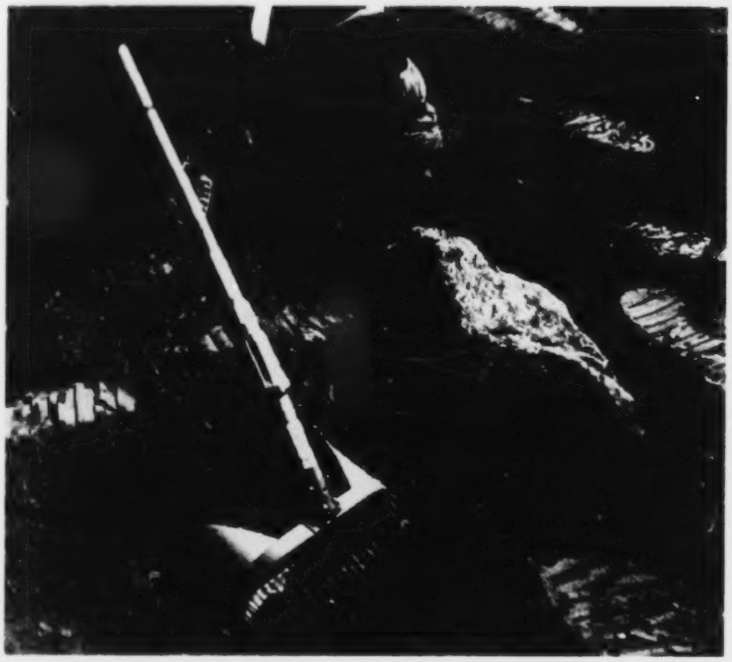
regolith. Be forewarned that the regolith samples in the Lunar Sample Disk are labeled "soil." Although it is everywhere, the regolith is thin, ranging from about two meters on the youngest maria to perhaps 20 meters in the oldest surfaces in the highlands. [*See the "Regolith Formation" activity on Pages 47–52.*]

Lunar regolith is a mixed blessing. On the one hand, it has mixed local material so that a shovelful contains most of the rock types that occur in an area. It even contains some rock fragments tossed in by impacts in remote regions. Thus, the regolith is a great rock collection. It also contains the record of impacts during the past several hundred million to a billion years, crucial information for understanding the rate of impact on Earth during that time. On the other hand, this impact record is not written very clearly and we have not come close to figuring it out as yet. The blanket of regolith also greatly obscures the details of the bedrock geology. This made field work during Apollo difficult and hinders our understanding of lunar history.

The regolith consists of what you'd expect from an impact-generated pile of debris. It contains rock and mineral fragments derived from the original bedrock. It also contains glassy particles formed by the impacts. In many lunar regoliths, half of the particles are composed of mineral fragments that are bound together by impact glass; scientists call these objects *agglutinates*. The chemical composition of the regolith reflects the composition of the bedrock underneath. Regolith in the highlands is rich in aluminum, as are highland rocks. Regolith in the maria is rich in iron and magnesium, major constituents of basalt. A little bit of mixing from beneath basalt layers or from distant highland locales occurs, but not enough to obscure the basic difference between the highlands and the maria.



Raking moon dirt

One of the most useful ways of obtaining samples of Moon rocks was to drag a rake through the regolith. This allowed rock fragments larger than about one centimeter to remain on tines of the rake, while smaller fragments fell through. Note the large range in the sizes of rock fragments. One large boulder lies near the rake, a medium-sized one is visible between the astronaut's feet, along with countless other pebbles. Most of the regolith is smaller than fine sand. The astronaut's footprints are distinct because the regolith is composed of a large percentage of tiny particles (about 20% is smaller than 0.02 millimeters).

A geologist-astronaut does field work on the Moon

Geologist Harrison H. Schmitt examines a large rock at the Apollo 17 landing site. This large boulder contains numerous rock fragments that were smashed together by the huge impact event that made the 750-kilometer Serentatis basin on the Moon.

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One of the great potential bits of information stored in the complex pile atop the lunar surface is the history of the Sun. The nearest star puts out prodigious amounts of particles called the *solar wind*. Composed mostly of hydrogen, helium, neon, carbon, and nitrogen, the solar wind particles strike the lunar surface and are implanted into mineral grains. The amounts build up with time. In principle, we can determine if conditions inside the Sun have changed over time by analyzing these solar wind products, especially the isotopic composition of them.

The same solar wind gases may prove useful when people establish permanent settlements on the Moon. Life support systems require the life-giving elements: hydrogen and oxygen (for water), carbon, and nitrogen. Plenty of oxygen is bound in the silicate, minerals of lunar rocks (about 50% by volume) and the solar wind provided the rest. So, when the astronauts were digging up lunar regolith for return to Earth, they were not merely sampling—they were prospecting!

MOON ROCKS

Geologists learn an amazing amount about a planet by examining photographs and using other types of remotely sensed data, but eventually they need to collect some samples. For example, although geologists determined unambigously from photographs that the maria are younger than the highlands, they did not know their absolute age, the age in years. Rocks also provide key tests to hypotheses. For instance, the maria were thought to be covered with lava flows, but we did not know for sure until we collected samples from them. Also, no method can accurately determine the chemical and mineralogical composition of a rock except laboratory analysis. Most important, samples provide surprises, telling us things we never expected. The highlands provide the best example of a geological surprise, and one with great consequences for our understanding of what Earth was like 4.5 billion years ago.

A fist-sized piece of the original lunar crust

This rock sample was collected during the Apollo 15 mission. It is an anorthosite, a rock composed of little else but the mineral feldspar. Anorthosites formed from the enormous magma system, the *lunar magma ocean*, that surrounded the newly formed Moon. Because of its importance in understanding the origin of the Moon's crust, the rock was nicknamed the "genesis rock."

Smash and mix, mix and melt

This rock returned by the Apollo 16 mission attests to the effects of impacts on a planet's crust. It is a hodgepodge of rock and mineral fragments, some of which themselves are complicated mishmashes of rock debris. Geologists call these complicated rocks *breccias*.

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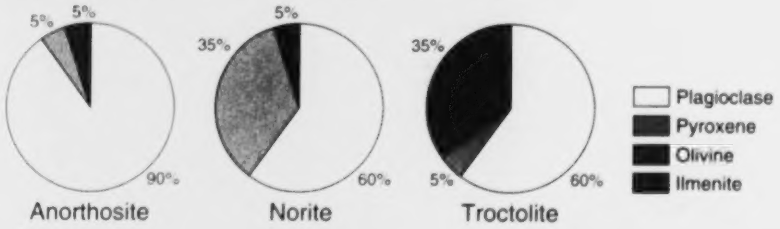
Highland rocks, the lunar magma ocean, and maybe a cataclysm

Strange as it may seem, the first highland rocks were collected during the first lunar landing, the Apollo 11 mission, which landed on a mare, Mare Tranquillitatis. Although most of the rocks collected were, indeed, basalts, some millimeter-sized rock fragments were quite different. They were composed chiefly of the mineral plagioclase feldspar; some fragments were composed of nothing but plagioclase. [*See the "Rock ABCs Fact Sheet" on Page 19.*] Such rocks are called *anorthosites.* Some scientists suggested that these fragments were blasted to the Apollo 11 landing site by distant impacts on highland terrain. Thus, they argued, the highlands are loaded with plagioclase. This was a bold extrapolation confirmed by subsequent Apollo missions to highland sites.

But this was not enough for some scientists. If the highlands are enriched in plagioclase, how did they get that way? One way is to accumulate it by flotation in a magma (molten rock). This happens in thick subterranean magma bodies on Earth. So, plagioclase floated in a magma. But if ALL the lunar highlands are enriched in plagioclase, then the magma must have been all over the Moon. The early Moon must have been covered by a global ocean of magma, now commonly referred to as the lunar *magma ocean.* Although some scientists still remain unconvinced about the veracity of the magma ocean hypothesis, nothing we have learned since has contradicted the idea that 4.5 billion years ago the Moon was covered by a layer of magma hundreds of kilometers thick. The idea has been extended to the young Earth as well, and even to Mars and some asteroids. And all this sprung forth because creative and bold scientists saw special importance in a few dozen white fragments of anorthosite strewn about in a pile of charcoal gray lunar regolith.

Mineral abundances in highland rocks



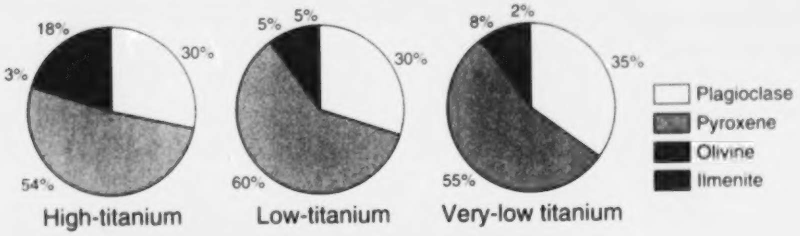
The highlands also contain other types of igneous rocks. The most abundant are called *norites* and *troctolites*, rocks composed of equal amounts of plagioclase and either olivine or pyroxene (both silicate minerals containing iron and magnesium). Age dating suggests that these rocks are slightly younger than the anorthosites and formed after the magma ocean had crystallized.

Highland rocks are difficult to work with because all that cratering, so evident in photographs of the highlands, has taken its toll on the rocks. Most highland rocks are complex mixtures of other rocks. The original igneous rocks have been melted, mixed, smashed, and generally abused by impacts during the Moon's first half billion years. We call these complicated rocks *breccias.* Some are so mixed up that they contain breccias within breccias within breccias. Most of the anorthosites, norites, and troctolites are actually rock fragments inside breccias. Separating them out is painstaking work.

An interesting thing about highland breccias, especially those we call impact melt breccias (rocks partly melted by an impact event), is that most of them fall into a relatively narrow span of ages, from about 3.85 to 4.0 billion years. This has led some scientists to propose (boldly again–lunar scientists don't seem to be timid!) that the Moon was bombarded with exceptional intensity during that narrow time interval. If it happened, it probably affected Earth as well, perhaps leading to production of the first sedimentary basins, and possibly inhibiting the formation of the first life on this planet or harming whatever life had developed by four billion years ago. This idea of a cataclysmic bombardment of the Moon is not yet proven. It could be that the apparent clustering in rock ages reflects poor sampling—we may only have obtained samples from one or two large impact basins. The idea can be tested by obtaining samples from many more localities on the Moon.

Many highland breccias and a few igneous rocks are enriched compared to other lunar samples in a set of elements not familiar to most of us. The elements are those that tend not to enter the abundant minerals in rocks. The result is that as a magma crystallizes the part that is still liquid becomes progressively richer in these special elements. The rocks that contain them are called *KREEP*, for potassium (chemical symbol K), rare-earth elements (abbreviated REE), and phosphorus (P). Most Moon specialists believe that KREEP represents the last dregs from the crystallization of the magma ocean. Huge impacts dug down to the lower crust of the Moon and excavated it, mixing it with other debris to form KREEPy breccias.

Mineral abundances in mare basalts



Multi-ringed masterpieces

The Moon has about 35 multi-ringed, circular impact features larger than 300 km in diameter. The one shown here, the Orientale basin, has three very prominent rings. The diameter of the outer one is 930 km. These immense craters might all have formed in a narrow time interval between 3.85 and 4.0 billion years ago. Scientists do not know for sure how the rings form during the impact.

The maria: lava flows and fountains of fire

The missions to mare areas brought back lots of samples of basalt. Basalts differ from the highlands rocks in having more olivine and pyroxene, and less plagioclase. Many of them also have surprisingly large amounts of an iron-titanium oxide mineral called *ilmenite*. The first batch had so much ilmenite (and some other related minerals) that they were called "high-titanium" mare basalts, in honor of the exceptional titanium contents compared to terrestrial basalts. The second mission, Apollo 12, returned basalts with lower titanium concentrations, so they were called "low-titanium" mare basalts. Subsequent missions, including an automated sample-return mission sent by the Soviet Union, returned some mare basalts with even lower titanium, so they were dubbed "very-low-titanium" basalts. Most scientists figure that mare basalts have a complete range in titanium abundance.

The shapes of the mineral grains and how they are intergrown in mare basalts indicate that these rocks formed in lava flows, some thin (perhaps a meter thick), others thicker (up to perhaps 30 meters). This is not unusual for basalt flows on Earth. Many lunar mare basalts also contain holes, called *vesicles*, which were formed by gas bubbles trapped when the lava solidified. Earth basalts also have them. On Earth, the abundant gases escaping from the lava are carbon dioxide and water vapor, accompanied by some sulfur and chlorine gases. We are not as sure what gases escaped from lunar lavas, although we know that water vapor was not one of them because there are no hints for the presence of water or water-bearing minerals in any Moon rock. The best bet is a mixture of carbon dioxide and carbon monoxide, with some sulfur gases added for good measure.

On Earth, when the amount of gas dissolved in magma (the name for lava still underground) becomes large, it escapes violently and causes an explosive eruption. In places such as Hawai'i, for example, the lava erupts in large fountains up to several hundred meters high. The lava falls to the ground in small pieces, producing a pyroclastic de-

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posit. This also happened on the Moon, producing the dark mantle deposits. One of these was sampled directly during the Apollo 17 mission. The sample, called the "orange soil," consists of numerous small orange glass beads. They are glass because they cooled rapidly, so there was not enough time to form and grow crystals in them.

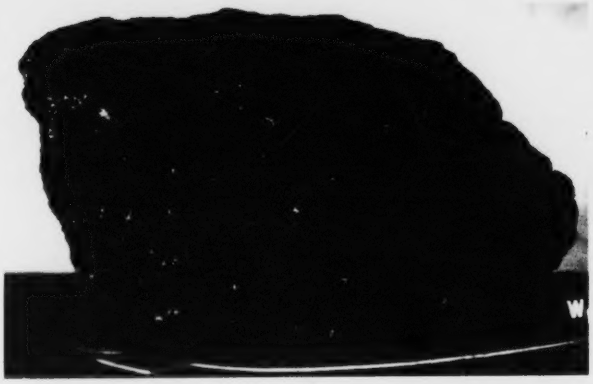
Small samples of pyroclastic glasses were also found at other sites. Some are green, others yellow, still others red. The differences in color reflect the amount of titanium they contain. The green have the least (about 1 weight percent) and the red contain the most (14 weight percent), more than even the highest titanium basalt.

Experiments conducted on mare basalts and pyroclastic glasses show that they formed when the interior of the Moon partially melted. (Rocks do not have a single melting temperature like pure substances. Instead they melt over a range of temperatures: 1000–1200°C for some basalts, for example.) The experiments also show that the melting took place at depths ranging from 100 to 500 km, and that the rocks that partially melted contained mostly olivine and pyroxene, with some ilmenite in the regions that formed the high-titanium basalts. An involved but sensible chain of reasoning indicates that these deep rocks rich in olivine and pyroxene formed from the lunar magma ocean: while plagioclase floated to form anorthosites in the highlands crust, the denser minerals olivine and pyroxene sank. So, although the anorthosites and mare basalts differ drastically in age and composition, the origins are intimately connected.

What's next?

Scientists are still working on the bounty returned by the Apollo missions. New analytical techniques and improved understanding of how geological processes work keep the field exciting and vibrant. Eventually we will need additional samples and some extensive field work to fully understand the Moon and how it came to be and continues to evolve. These sampling and field expeditions will probably be done by a combination of robotic and piloted spacecraft.

In the meantime, Nature has provided a bonus: samples from the Moon come to us free of charge in the form of lunar meteorites. About 10 have been identified so far, one found in Australia and the rest in Antarctica. We are sure that they come from the Moon on the basis of appearance and chemical and isotopic composition, but of course we do not know from where on the Moon they come. These samples have helped support the magma ocean idea. Most important, knowing that meteorites can be delivered



A piece of a lava flow

This typical sample of a mare basal is composed mostly of brown pyroxene (grayish in the photo) and white feldspar. The holes in the sample are frozen gas bubbles. Some basalt samples have many such bubbles (called vesicles by geologists), whereas others have none.

From the Moon, free of charge

The first lunar meteorite discovered in Antarctica hails from the lunar highlands and, like most highlands rocks, it is an impact breccia. The lunar meteorites prove that objects can be blasted off sizable objects without melting them, adding credence to the idea that a group of nine meteorites comes from Mars.

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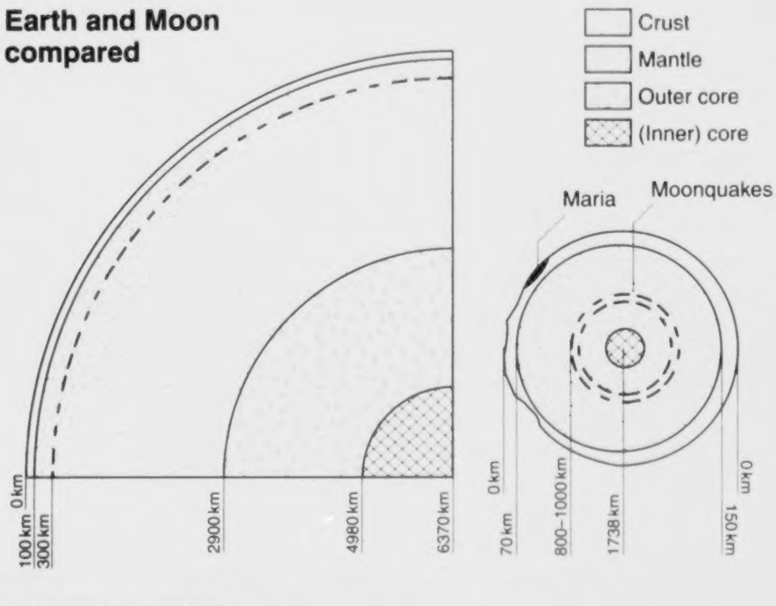
to Earth by impacts on the Moon lends credence to the idea that we have some meteorites from Mars. The Martian meteorites, collectively called *SNC meteorites*, almost certainly come from a relatively young igneous province on Mars called the Tharsus Plateau. If we did not know so much about the Moon we would never have been able to identify meteorites from the Moon, and, therefore, would not have been able to argue as convincingly that some meteorites come from Mars.

MOONQUAKES, THE MOON'S INTERIOR, AND THE MYSTERIOUS MAGNETIC FIELD

The Moon does not shake, rattle, and roll as Earth does. Almost all moonquakes are smaller than Earth's constant grumblings. The largest quakes reach only about magnitude 5 (strong enough to cause dishes to fall out of cabinets), and these occur about once a year. This is clear evidence that the Moon is not at present geologically active. No internal motions drive crustal plates as on Earth, or initiate hot spots to give rise to volcanic provinces like Hawai'i. This seismic inactivity is a wonderful virtue in the eyes of astronomers. Combined with the lack of an atmosphere to cause stars to twinkle, the low moonquake activity makes the Moon an ideal place to install telescopes.

We know about moonquakes from four seismometers set up by the Apollo missions. Besides telling us how many and how strong moonquakes are, the data acquired by the Apollo seismic network help us figure out something about the nature of the Moon's interior. On Earth, seismology has allowed us to know that the planet has a thin crust (20-60 km over continents, 8-10 km over ocean basins), a thick silicate mantle (down to 2900 km), and a large metallic iron core (2900 km to the center at 6370 km). The Moon is quite different. The crust is thicker than Earth's continental crust, ranging from 70 km on the Earth-facing side to perhaps 150 km on the farside. The mare basalts represent a thin veneer on this mostly plagioclase-rich crust, averaging only about 1 km in thickness (inferred mostly from photogeological studies). Evidence from samples collected on the rims of the large basins Imbrium and Serentatis and from remote sensing instruments carried onboard two Apollo missions suggests that the lower crust may not contain as much plagioclase as does the upper half of the crust. Beneath the crust is the lunar mantle, which is the largest part of the Moon. There might be a difference in rock types above and below a depth of 500 km, perhaps representing the depth of the lunar magma ocean. Beneath the mantle lies a small lunar core made of metallic iron. The size of the core is highly uncertain, with estimates ranging from about 100 km to 400 km.


Earth and Moon compared

Inside the Moon and Earth

Scientists have learned what Earth and the Moon are like inside by several techniques, the most important of which is seismology, the study of earthquake (and, of course) moonquake waves. Earth has a much larger metallic core than does the Moon.

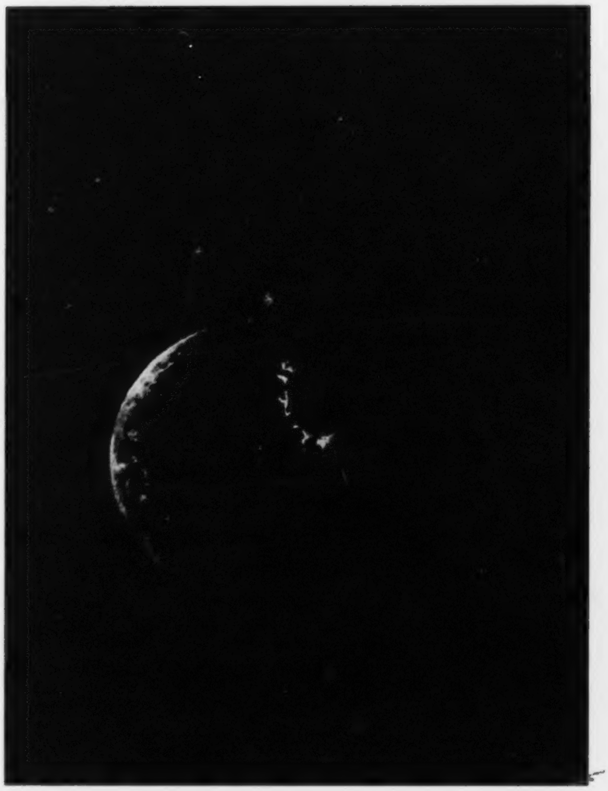
That little core is important, though. The Moon does not have much of a magnetic field, so the lunar core is not generating magnetism the way Earth's core is. Nevertheless, it did in the past. Lunar rocks are magnetized, and the strength of the magnetic field has been measured by special techniques. Also, older rocks have stronger magnetism, suggesting that the Moon's magnetic field was stronger in the distant past, and then decreased to its weak present state. Why this happened is unknown. What is known is this: you cannot navigate around the Moon using a compass!

There are other mysteries about the Moon's magnetism. Although the field was always weak and is extremely weak now, there are small areas on the Moon that have magnetic fields much stronger than the surrounding regions. These magnetic anomalies have not been figured out. Some scientists have associated them with the effects of large, basin-forming impacts. Others have suggested that the ionized gases produced when comets impact the Moon might give rise to strong magnetic anomalies in the crater ejecta. The jury is still out.

THE MOON'S ORIGIN: A BIG WHACK ON THE GROWING EARTH

For a long time, the most elusive mystery about the Moon was how it formed. The problem baffled philosophers and scientists for hundreds of years. All of the hypotheses advanced for lunar origin had fatal flaws, even though partisans tried tenaciously to explain away the defects. The capture hypothesis, which depicts capture of a fully formed Moon by Earth, suffered from improbability. Close encounter with Earth would either result in a collision or fling the Moon into a different orbit around the Sun, probably never to meet up with Earth again. The fission hypothesis, in which the primitive Earth spins so fast that a blob flies off, could not explain how Earth got to be spinning so fast (once every 2.5 hours) and why Earth and the Moon no longer spin that fast. The double-planet hypothesis pictures Earth and the Moon forming together, a two-body system from the start. This idea has trouble explaining Earth's rotation rate and how the moon-forming material got into orbit around Earth and stayed there, rather than falling to Earth. (These problems with total amount of spinning involve both Earth's rotation and the Moon's motion around Earth. The amount of rotation and revolving is quantified by a physical property called angular momentum.) The problem was so frustrating that some scientists suggested that maybe science had proved that the Moon does not exist!

The annoying problems with the classical hypotheses of lunar origin led scientists to consider alternatives. This search led to the seemingly outlandish idea that the Moon formed when a projectile



WHACK!

The Moon may have formed when an object the size of the planet Mars smashed into Earth when our future home was about 90% constructed. This fierce event made Earth larger and blasted off vaporized and melted material into orbit. The Moon formed from this debris. This painting was created by William K. Hartmann, one of the scientists who invented the giant impact hypothesis for lunar origin.

the size of the planet Mars (half Earth's radius and one-tenth its mass) smashed into Earth when it had grown to about 90% of its present size. The resulting explosion sent vast quantities of heated material into orbit around Earth, and the Moon formed from this debris. This new hypothesis, which blossomed in 1984 from seeds planted in the mid-1970s, is called the *giant impact theory*. It explains the way Earth spins and why Earth has a larger metallic core than does the Moon. Furthermore, modern theories for how the planets are assembled from smaller bodies, which were assembled from still smaller ones, predict that when Earth was almost done forming, there would have been a body nearby with a mass about one-tenth that of Earth. Thus, the giant impact hypothesized to have formed the Moon is not an implausible event. The chances are so high, in fact, that it might have been unavoidable.

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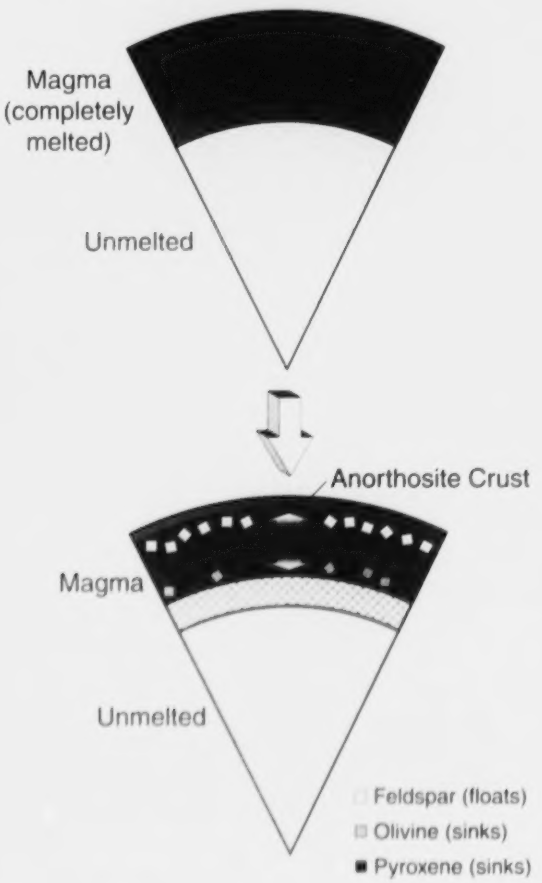
One would think that an impact between an almost Earth-sized planet and a Mars-sized planet would be catastrophic. The energy involved is incomprehensible. Much more than a trillion trillion tons of material vaporized and melted. In some places in the cloud around, Earth temperatures exceeded 10,000°C. A fledgling planet the size of Mars was incorporated into Earth, its metallic core and all, never to be seen again. Yes, this sounds catastrophic. But out of it all, the Moon was created and Earth grew to almost its final size. Without this violent event early in the Solar System's history, there would be no Moon in Earth's sky, and Earth would not be rotating as fast as it is because the big impact spun it up. Days might even last a year. But then, maybe we would not be here to notice.

The lunar magma ocean



Sinking and floating in an ocean of magma

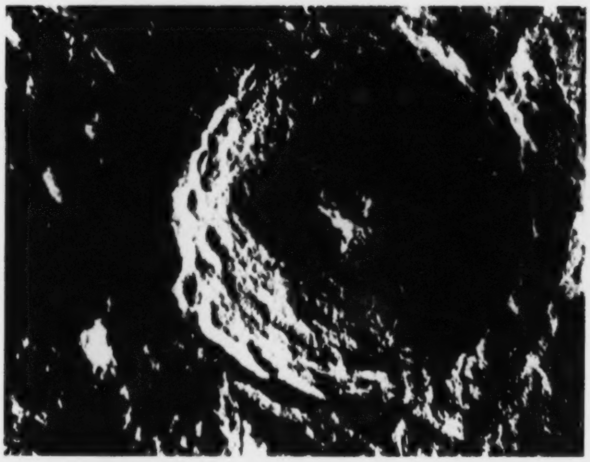
Soon after it formed, the Moon was surrounded by a huge shell of molten rock called the lunar magma ocean. As crystals formed in it, the denser ones such as olivine and pyroxene sank and the less dense ones, such as feldspar, floated upwards, forming the original anorthosite crust on the Moon. Dropping toothpicks and pennies into a glass of water shows the process: the toothpicks (representing feldspar) float and the pennies (olivine and pyroxene) sink.

A BRIEF HISTORY OF THE MOON

We know the general outlines of what happened to the Moon after it was formed by a giant impact. The first notable event, which may have been a consequence of the giant impact, was the formation and crystallization of the magma ocean. Nobody knows how deep it was, but the best guess is that it was at least 500 km deep. The first minerals to form in this mind-boggling magmatic system were the iron and magnesium silicates olivine and pyroxene. They were denser than the magma, so they sank, like rocks in a pond, though not as fast. Eventually, plagioclase feldspar formed, and because it was less dense than the magma, began to float to the top, like bubbles in cola. It accumulated and produced mountains of anorthosite, producing the first lunar crust. The magma ocean phase ended by about 4.4 billion years ago. [*See the "Differentiation" activity on Pages 57–60.*]

Almost as soon as the crust had formed, perhaps while it was still forming, other types of magmas that would form the norites and troctolites in the highlands crust began to form deep in the Moon. A great mystery is *where* inside the Moon and how deep. Many lunar specialists believe the magmas derived from unmelted Moon stuff beneath the magma ocean. In any case, these magmas rose and infiltrated the anorthosite crust, forming large and small rock bodies, and perhaps even erupting onto the surface. Some of the magmas reacted chemically with the dregs of the magma ocean (KREEP) and others may have dissolved some of the anorthosite. This period of lunar history ended about 4.0 billion years ago.

All during these first epochs, left-over projectiles continued to bombard the Moon, modifying the rocks soon after they formed. The crust was mixed to a depth of at least a few kilometers, perhaps as much as 20 km, as if a gigantic tractor had plowed the lunar crust. Though not yet proven, the rate of impact may have declined between 4.5 and 4.0 billion years ago, but then grew dramatically, producing most of the large basins visible on the Moon. This cataclysmic



Anatomy of an impact crater

The crater Tycho in the southern highlands on the lunar nearside is 85 kilometers across. Its terraced walls rise 3 to 4 kilometers above its floor. Its rim rises above the surrounding terrain, and its floor sits below it. Smooth material on the floor of the crater consists of impact-melted rock that flowed like lava across the growing floor in the later stages of excavation. In response to the huge increase then decrease in pressure, mountains two kilometers high rose from its floor, bringing up material from as much as ten kilometers in the crust. The blanket of material surrounding the crater is called the ejecta blanket; this pile of debris becomes progressively thinner away from the crater (especially evident on the left of the photo).

Although not visible on this photograph, large craters like Tycho also have rays emanating from them. Rays form when materials thrown out of the crater land and excavate more of the lunar landscape along arcuate paths. The Tycho event caused a landslide and several secondary impacts at the Apollo 17 landing site, over 2000 kilometers away. Analysis of samples collected during the Apollo 17 mission indicates that these events took place 110 million years ago. Thus, Tycho formed 110 million years ago.

bombardment is postulated to have lasted from 4.0 to 3.85 billion years ago. [*See the "Impact Craters" activity on Pages 61–70, and the "Regolith Formation" activity on Pages 47–52.*]

Once the bombardment rate had settled down, the maria could form. Basalts like those making up the dark mare surfaces formed before 3.85 billion years ago, but not as voluminously as later, and the enormous bombardment rate demolished whatever lava plains formed. However, between 3.7 and about 2.5 billion years ago (the lower limit is highly uncertain), lavas flowed across the lunar surface, forming the maria and decorating the Moon's face. Along with the basalts came pyroclastic eruptions, high fountains of fire that launched glowing droplets of molten basalt on flights up to a few hundred kilometers.

Since mare volcanism ceased, impact has been the only geological force at work on the Moon. Some impressive craters have been made, such as Copernicus (90 km across) and Tycho (85 km). These flung bright rays of material across the dark lunar landscape, adding more decoration. In fact, some of the material blasted from Tycho caused a debris slide at what would become the Apollo 17 landing site. Samples from this site indicate that the landslide and some associated craters formed about 110 million years ago. This, therefore, is the age of the crater Tycho. It is a triumph of geological savvy that we were able to date an impact crater that lies over 2000 km from the place we landed!

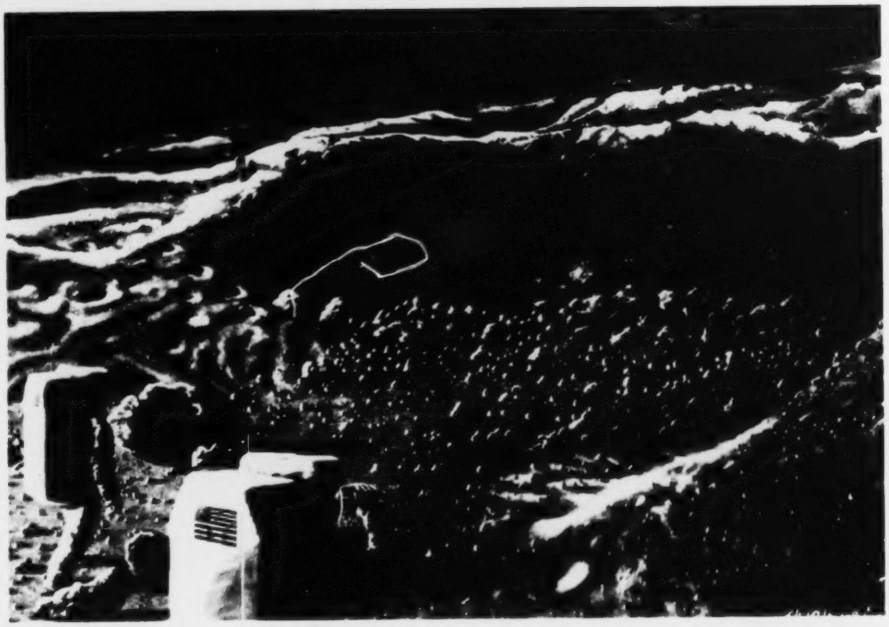
The impacts during the past billions of years also have mixed the upper several meters of crust to make the powdery lunar regolith. The Sun has continued to implant a tiny amount of itself into the regolith, giving us its cryptic record and providing resources for future explorers. And recently, only seconds ago in geologic time, a few interplanetary travelers left their footprints here and there on the dusty ground.

THE MOON AND EARTH: INEXORABLY INTERTWINED

The Moon ought to be especially alluring to people curious about Earth. The two bodies formed near each other, formed mantles and crusts early, shared the same post-formational bombardment, and have been bathed in the same flux of sunlight and solar particles for the past 4.5 billion years. Here are a few examples of the surprising ways in which lunar science can contribute to understanding how Earth works and to unraveling its geological history.

Origin of the Earth-Moon System. No matter how the Moon formed, its creation must have had dramatic effects on Earth. Although most scientists have concluded that the Moon formed as a result of an enormous impact onto the growing Earth, we do not know much about the details of that stupendous event. We do not know if the Moon was made mostly from Earth materials or mostly projectile, the kinds of chemical reactions that would have taken place in the melt-vapor cloud, and precisely how the Moon was assembled from this cloud.

Magma oceans. The concept that the Moon had a magma ocean has been a central tenet of lunar science since it sprung from fertile minds after the



Geology at a Moon Base

The best geology is done in the field. To understand rocks we must examine them up close, map their distributions, see the structures in them, and chip off samples when necessary. The field geology done during the Apollo missions was hampered by the lack of time the astronauts could devote to it. But that will change when people live permanently on the Moon. Geologists will be able to spend as much time as they need to decipher the story recorded by lunar rock formations. This painting shows three astronauts (one in the distance) examining the outside of a lava tube, an underground conduit that carried red-hot lava to an eruption site perhaps hundreds of kilometers away.

return of the first lunar samples in 1969. It is now being applied to Earth, Mars, and asteroids. This view of the early stages of planet development is vastly different from the view in the 1950s and 1960s. Back then, most (not all) scientists believed the planets assembled cold, and then heated up. The realization that the Moon had a magma ocean changed all that and has led to a whole new way of looking at Earth's earliest history.

Early bombardment history of Earth and Moon. The thousands of craters on the Moon's surface chronicle the impact record of Earth. Most of the craters formed before 3.9 billion years ago. Some scientists argue that the Moon suffered a cataclysmic bombardment (a drastic increase in the number of impacting projectiles) between 3.85 and 4.0 billion years ago. If this happened and Earth was subjected to the blitzkrieg as well, then development of Earth's earliest crust would have been affected. The intense bombardment could also have influenced the development of life, perhaps delaying its appearance.

Impacts, extinctions, and the evolution of life on Earth. The mechanisms of evolution and mass extinctions are not understood. One possibility is that some mass-extinction events were caused by periodic increases in the rate of impact on Earth. For example, the mass extinctions, which included the demise of the dinosaurs, at the end of the Cretaceous period (65 million years ago) may have been caused by a large impact event. Attempts to test the idea by dating impact craters on Earth are doomed because there are too few of them. But the Moon has plenty of craters formed during the past 600 million years (the period for which we have a rich fossil record). These could be dated and the reality of spikes in the impact record could be tested.

How geologic processes operate. The Moon is a natural laboratory for the study of some of the geologic processes that have shaped Earth. It is a great place to study the details of how impact craters form because there are so many well-preserved craters in an enormous range of sizes. It is also one of the places where volcanism has operated, but at lower gravity than on either Earth or Mars.

LIFE AND WORK AT A MOON BASE

People will someday return to the Moon. When they do, it will be to stay. They will build a base on the Moon, the first settlement in the beginning of an interplanetary migration that will eventually take them throughout the Solar System.

There will be lots to do at a lunar base. Geologists will study the Moon with the intensity and vigor

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they do on Earth, with emphasis on field studies. Astronomers will make magnificent observations of the universe. Solar scientists will study the solar wind directly and investigate past activity trapped in layers of regolith. Writers and artists will be inspired by a landscape so different from Earth's. Life scientists will study how people adapt to a gravity field one-sixth as strong as Earth's, and figure out how to grow plants in lunar greenhouses. Engineers will investigate how to keep a complex facility operating continuously in a hostile environment. Mining and chemical engineers will determine how to extract resources from Moon rocks and regolith. The seemingly dry lunar surface contains plenty of the ingredients to support life at a Moon base (oxygen and hydrogen for water, nitrogen and carbon for the growth of plants), including the construction materials to build and maintain the base (regolith can be molded into bricks; iron, titanium, and aluminum can be smelted and forged into tools and building materials). It will be an exciting, high-tech, faraway place inhabited by adventurous souls. [*See the Unit 3 activities beginning on Page 99.*]

Safe haven for precious rocks

NASA stores the lunar sample collection in a specially constructed facility called the Lunar Curatorial Facility at the Johnson Space Center in Houston, Texas. The priceless materials remain in a nitrogen atmosphere, which is far less reactive chemically than normal oxygen-rich air. Scientists working in the facility wear lint-free outfits affectionately known as "bunny suits," and handle the samples in glove boxes. In this photograph, Roberta Score is examining a piece of an Apollo 16 rock, while Andrea Mosie (left) looks on.

WHERE MOON ROCKS HANG OUT

Since arrival on Earth, lunar samples have been treated with the respect they deserve. Most of the treasure of Apollo is stored at the Lunar Curatorial Facility at the Johnson Space Center, Houston, Texas. A small percentage is stored in an auxiliary facility at Brooks Air Force Base near San Antonio, Texas, placed there in case a disaster, such as a hurricane, befalls Houston and the samples are destroyed. Many small samples are also in the laboratories of investigators around the world, where enthusiastic scientists keep trying to wring out the Moon's secrets.

The Curatorial Facility is one of the cleanest places you'll ever see. To go inside, you must wear white suits, boots, hats, and gloves, outfits affectionately known as "bunny suits." Wipe a gloved hand on a stainless steel cabinet and you will not find a trace of dust because the air is filtered to remove potential contaminating particles.

The samples are stored in a large vault, and only one at a time is moved to a glove box. You can pick up the rocks by jamming your hands into a pair of the black rubber gloves, allowing you to turn a rock over, to sense its mass and density, to connect with it. A stereomicroscope allows you to look at it closely. If you decide you need a sample, and of course you have been approved to obtain one, then expert lunar sample processors take over. The sample is photographed before and after the new sample is chipped off. This is time consuming, but valuable to be sure we know the relationships of all samples to each other. In many cases, we can determine the orientation a specific part of a rock was in on the surface of the Moon before collection.

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Scientists as poets

Scientists do not view the world in purely objective ways. Each has biases and a unique way of looking at the world. Science is not done solely with piles of data, hundreds of graphs, or pages of equations. It is done with the heart and soul, too. Sometimes a scientist is moved to write about it in elegant prose like that written by Loren Eisley or in poetry, like the poem below written by Professor Carlé Pieters of Brown University. Dr. Pieters holds her doctorate from MIT and is an expert in remote sensing of planetary surfaces. She is especially well known for her telescopic observations of the Moon. The poem first appeared in the frontispiece of *Origin of the Moon*, published by the Lunar and Planetary Institute.

The Original Moon

Four and a half æons ago
a dark, dusty cloud deformed.
Sun became star; Earth became large,
and Moon, a new world, was born.

This Earth/Moon pair, once linked so close,
would later be forced apart.
Images of young intimate ties
we only perceive in part.

Both Earth and Moon were strongly stripped
of their mantle siderophiles.
But Moon alone was doomed to thirst
from depletion of volatiles.

Moon holds secrets of ages past
when planets dueled for space.
As primordial crust evolved
raw violence reworked Moon's face.

After the first half billion years
huge permanent scars appeared;
ancient feldspathic crust survived
with a mafic mantle mirror.

But then there grew from half-lived depths
a new warmth set free inside.
Rivers and floods of partial melt
resurfaced the low 'frontside'.

Thus evolved the Original Moon
in those turbulent times.
Now we paint from fragments of clues
the reasons and the rhymes:

Sister planet;
Modified clone;
Captured migrant;
Big splash disowned?

The Truth in some or all of these
will tickle, delight,
temper, and tease.

— Carlé Pieters

Moon ABCs Fact Sheet

Property	Earth	Moon	Brain Busters
Equatorial diameter	12,756 km	3,476 km	*How long would it take to drive* around the Moon's equator at 80 km per hour?
Surface area	510 million square km	37.8 million square km	The Moon's surface area is similar to that of one of Earth's continents. Which one?
Mass	5.98 x 10^{24} kg	7.35 x 10^{22} kg	What percentage of Earth's mass is the Moon's mass?
Volume	---	---	Can you calculate the volumes of Earth and the Moon?
Density	5.52 grams per cubic cm	3.34 grams per cubic cm	Check this by calculating the density from the mass and volume.
Surface gravity	9.8 m/sec/sec	1.63 m/sec/sec	What fraction of Earth's gravity is the Moon's gravity?
Crust	Silicate rocks. Continents dominated by granites. Ocean crust dominated by basalt.	Silicate rocks. Highlands dominated by feldspar-rich rocks and maria by basalt.	What portion of each body is crust?
Mantle	Silicate rocks dominated by minerals containing iron and magnesium.	Similar to Earth.	Collect some silicate rocks and determine the density. Is the density greater or lesser than the Earth/Moon's density? Why?

Moon ABCs Fact Sheet

Property	Earth	Moon	Brain Busters
Core	Iron, nickel metal	Same, but core is much smaller	What portion of each body is core?
Sediment or Regolith	Silicon and oxygen bound in minerals that contain water, plus organic materials.	Silicon and oxygen bound in minerals, glass produced by meteorite impacts, small amounts of gases (e.g., hydrogen) implanted by the solar wind. No water or organic materials.	Do you think life ever existed on the Moon? Why or why not?
Atmosphere (main constituents)	78 % nitrogen, 21 % oxygen	Basically none. Some carbon gases (CO_2, CO, and methane), but very little of them. Pressure is about one-trillionth of Earth's atmospheric pressure.	Could you breathe the lunar atmosphere?
Length of day (sidereal rotation period)	23.93 hours	27.3 Earth days	How long does daylight last on the Moon?
Surface temperature	Air temperature ranges from -88°C (winter in polar regions) to 58°C (summer in tropical regions).	Surface temperature ranges from -193°C (night in polar regions) to 111°C (day in equatorial regions).	Why are the temperatures of Earth and the Moon so different?
Surface features	25 % land (seven continents) with varied terrain of mountains, plains, river valleys. Ocean floor characterized by mountains, plains.	84 % heavily-cratered highlands. 16 % basalt-covered maria. Impact craters--some with bright rays, crater chains, and rilles.	Compare maps of Earth and the Moon. Is there any evidence that plate tectonics operated on the Moon?

Rock ABCs Fact Sheet

What are minerals?

Minerals are naturally occurring solids that have definite chemical compositions and are crystalline. Crystals are individual pieces of minerals. The most important characteristic of crystals is the orderly internal arrangement of atoms. This internal order causes the beautiful crystal shapes.

MINERAL	ELEMENTS	APPEARANCE IN MOON ROCKS
Plagioclase feldspar	calcium (Ca), aluminum, silicon (Si), Oxygen (O)	Whitish to translucent grayish; usually occurs as grains longer than they are wide.
Pyroxene	iron (Fe), magnesium, (Mg), calcium (Ca), silicon (Si), oxygen (O)	Brown to black; grains usually longer than wide in mare basalts, somewhat squarish in highland rocks.
Olivine	iron (Fe), magnesium (Mg), silicon (Si), oxygen (O)	Greenish; usually occurs as roundish crystals.
Ilmenite	iron (Fe), titanium (Ti), oxygen (O)	Black, elongated to squarish crystals.

What are rocks?

Rocks are naturally occurring solids composed of one or more minerals. At least two abundant minerals usually occur in a rock, along with several others. The minerals are intergrown in intricate ways that depend on how the rock formed. Rocks are classified on the basis of the abundance of the minerals they contain, sizes of individual crystals, and the process that formed the rocks.

Mineral abundances (percents) in Moon rocks

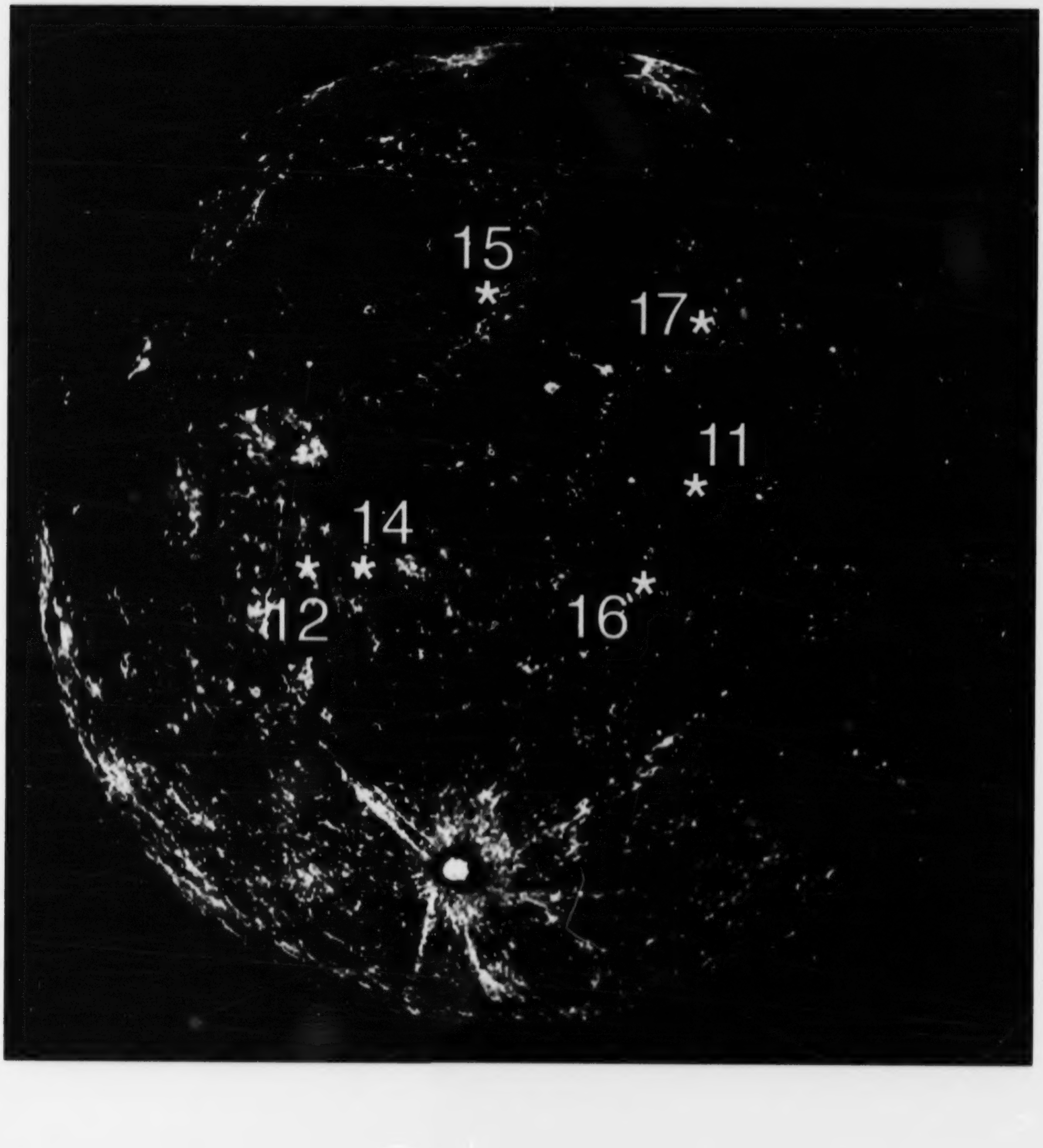
	Plagioclase	Pyroxene	Olivine	Ilmenite
Highland rocks				
Anorthosite	90%	5%	5%	0%
Norite	60%	35%	5%	0%
Troctolite	60%	5%	35%	0%
Mare basalts				
High-titanium	30%	54%	3%	18%
Low-titanium	30%	60%	5%	5%
Very-low titanium	35%	55%	8%	2%

Progress in Lunar Science

Topic	1959 View	Early 1969 View	Post-Apollo View 1975	1994 View
Surface Material	Volcanic ash, impact debris, fluffy dust.	Probably impact debris, but other ideas not ruled out.	Impact debris derived from underlying rock layer or bare rock?	Regolith formation now modeled by computer.
Craters	Impact or volcanic?	Majority impact; unknown percentage of volcanic origin.	Almost all impact; many rocks affected by impacts.	More is known about how material is thrown out of a growing crater.
Maria	Impact or volcanic?	Probably volcanic.	Definitely volcanic.	Better understanding of eruption conditions.
Composition of Maria	Unknown	Probably basalt.	Definitely basalt.	Wide variety of basalt types.
Composition of Highlands	Unknown	Probably rocks with more aluminum and less iron than mare basalt.	Rocks high in aluminum with large percentages of feldspar.	Wide variety of rock types, but all containing more aluminum than mare basalt.
Composition of Farside	Unknown	Mare areas less abundant than on the nearside.	Highlands similar to nearside highlands.	Highlands containing rocks rich in aluminum.
Composition of Mantle	Unknown	No progress.	High content of olivine and pyroxene.	Amounts and composition of olivine and pyroxene vary.
Nature of Core	Smaller than Earth's.	No progress.	Smaller than 500 km.	Smaller than 250 km.
Volatiles (such as water) and Organic Compounds	Unknown, though some scientists thought water had flowed on Moon's surface.	No progress.	Moon contains no water or organic compounds, and other volatiles much lower than on Earth.	There might be water brought in by impacting comets and trapped in very cold places at the poles.
Rock Ages	Unknown	Uncertain, but probably ancient (more than a few billion years).	Highlands: older than 3.9 billion years. Maria: 3.2 - 3.7 billion years.	Highlands: most igneous rocks older than 4.1 billion years, with anorthosites 4.4 billion years. Maria: some as young as about 2 billion years others as old as 4.3 billion years.
Magma Ocean	Not even conceived.	No progress.	Highlands formed from huge magma system more than 300km deep.	Anorthosites formed from magma ocean; other highland rocks formed after that.
Origin	Captured, derived from Earth, or dual planet?	No progress.	Moon and Earth probably related, so capture idea less likely.	Giant impact on Earth, followed by formation of Moon in Earth orbit.

Nearside of the Moon

Apollo Landing Sites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Unit 1

Pre-Apollo Activities

Distance to the Moon
Diameter of the Moon
Reaping Rocks

Before Apollo 11 astronauts Neil A. Armstrong and Edwin E. "Buzz" Aldrin Jr. stepped on the Moon on July 20, 1969, people had studied the Moon by eye, telescope, and images from spacecraft. The theme of Unit 1 is a basic introduction to the Moon -- how it looks from Earth, how far away it is, and how big it is. The activities allow students to make comparisons between the Moon and Earth as well as to make predictions about the Moon rocks.

Encourage students to sketch and describe nightly observations of the Moon and keep a written record of date and time. Nightly charting of the Moon helps students recognize Moon phases as well as the bright and dark terrains.

Scale models and proportional relationships are featured in the first two activities. The "Distance to the Moon" and "Diameter of the Moon" activities introduce students to techniques of measuring distances in space indirectly.

This unit also includes an activity to collect and study rocks called "Reaping Rocks." This activity should follow a more comprehensive lesson on basic rock and mineral identification. The activity also extends learning to the Moon and asks students to predict how their rock collections will compare with lunar samples.

A Resource Section for Unit 1 is on Page 24.

Resource Section

This list presents possible independent and commercial sources of items to complement the activities in Unit 1. The sources are offered without recommendation or endorsement by NASA. Inquiries should be made directly to the appropriate source to determine availability, cost, and ordering information before sending money. Contact your NASA Teacher Resource Center (see Pages 147-148) for more lists of resources available directly from the National Aeronautics and Space Administration.

Maps

The Earth's Moon by National Geographic Society. Wall map showing nearside and farside. Also includes graphics with captions explaining eclipses, lunar phases, tides, and other phenomena. U.S. and Soviet landing/impact sites are shown. The reverse side has an index of lunar named features and selected photographs from the Apollo missions.
National Geographic Society
Educational Services, Department 91
Washington, D.C. 20036
1-800-368-2728 or FAX 1-301-921-1575

Giant Moon Map by Rand McNally. Wall map showing the nearside. Contact Rand McNally directly, or order it through:
Astronomical Society of the Pacific
390 Ashton Ave.
San Francisco, CA 94112
1-415-337-2624

Maps of Earth, Moon, Mars, etc.
U.S. Geological Survey Map Sales
Box 25286
Denver Federal Center
Denver, CO 80225
303-236-7477
(Ask for Customer Service)

Globes

Edmund Scientific Co.
101 E. Gloucester Pike
Barrington, NJ 08007-1380
1-609-573-6270 or FAX 1-609-573-6295

Lunar Phase Calendars

Celestial Products
P.O. Box 801
Middleburg, VA 22117
1-800-235-3783 or FAX 1-703-338-4042

Earth Rock Sample Sets

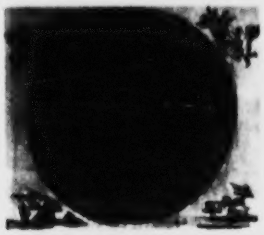
Ward's Natural Science Establishment, Inc.
P.O. Box 92912
Rochester, NY 14692-9012
1-800-962-2660

Slides

Glorious Eclipses slide set
Astronomical Society of the Pacific
390 Ashton Ave.
San Francisco, CA 94112
1-415-337-2624

Other Teacher's Guide

Return to the Moon: Moon Activities Teacher's Guide, 1990
Curriculum package consisting of a background book and classroom activities covering the Earth-Moon system, going to the Moon, and planning a future lunar mining base.
Challenger Center for Space Science Education
1101 King Street, Suite 190
Alexandria, VA 22314
1-703-683-9740



Distance to the Moon

Purpose

To calculate the distance between scale models of Earth and the Moon.

Background

As long as people have looked at the Moon, they have wondered how far away it is from Earth. The average distance to the Moon is 382,500 km. The distance varies because the Moon travels around Earth in an elliptical orbit. At perigee, the point at which the Moon is closest to Earth, the distance is approximately 360,000 km. At apogee, the point at which the Moon is farthest from Earth, the distance is approximately 405,000 km.

Distance from Earth to the Moon for a given date can be obtained by asking a local planetarium staff. Students interested in astronomy may enjoy looking at *The Astronomical Almanac* printed yearly by the U.S. Government printing office. When the Apollo 11 crew landed on the Moon on July 20, 1969, they were 393,309 km away from home.

In this activity students will use simple sports balls as **scale** models of Earth and the Moon. Given the astronomical distance between Earth and the Moon, students will determine the scale of the model system and the distance that must separate the two models.

The "Moon ABCs Fact Sheet" lists the Earth's diameter as 12,756 km and the Moon's diameter as 3,476 km. Therefore, the Moon's diameter is 27.25% of Earth's diameter. An official basketball has a diameter of 24 cm. This can serve as a model for Earth. A tennis ball has a diameter of 6.9 cm which is close to 27.25% of the basketball. (The tennis ball is actually 28.8% the size of the basketball.) These values are very close to the size relationship between Earth and the Moon. The tennis ball, therefore, can be used as a model of the Moon.

The scale of the model system is determined by setting the diameter of the basketball equal to the diameter of Earth. This is written as a simple relationship shown below:

$$24 \text{ cm} = 12{,}756 \text{ km}$$

Expressed more simply, 1 cm in the model system equals 531.5 km in space:

$$1 \text{ cm} = 531.5 \text{ km}$$

Distance to the Moon

Using this scale, the basketball-tennis ball separation in centimeters (**x**) is derived:

$$\mathbf{x} = \frac{382{,}500 \text{ km}}{531.5 \text{ km}} = 719.7 \text{ cm}$$

The value **x** may be rounded to 720 cm and converted to meters so that the students need to place the basketball and tennis ball 7.2 m apart.

Preparation

Review and prepare materials listed on the student sheet.
If it is not possible to obtain an official-size basketball and tennis ball, then you can use other spherical objects or circles drawn on paper. Clay balls may be used as models. For example, for two clay balls, 10 cm diameter and 2.7 cm diameter, the scale is 1 cm = 1,275.6 km. At this scale, students need to separate the clay balls by 3 m.

In Class

Divide the students into cooperative groups. Students must keep track of units of measure.

Wrap Up

Did the students have an accurate idea of the size relationship between Earth and the Moon before doing this activity?

Did the effect of separating the scale models help them visualize the distance to the Moon?

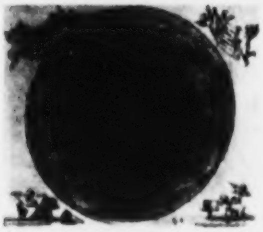
Extensions

1. How long did it take Apollo astronauts to travel to the Moon?

2. Have students measure the circumferences of various spheres so that each group uses a different pair of models.

3. Instead of using the average distance to the Moon, use the distance from July 20, 1969, to recall the Apollo 11 landing or use the distance for today.

Distance to the Moon



Purpose

To calculate the distance between scale models of Earth and the Moon.

Key Word

scale

Materials

"Moon ABCs Fact Sheet"
sports balls
calculator
meter tape

Procedure

1. If Earth were the size of an official basketball, then the Moon would be the size of: another basketball? soccer ball? baseball? tennis ball? golf ball? marble?

2. The diameter of Earth in kilometers is:

3. The diameter of the Moon in kilometers is:

4. What percentage of Earth's diameter is the Moon's diameter?

5. Use the list below to change or confirm your answer to Question 1.

	diameter in cm
official basketball	24
size 5 soccer ball	22
official baseball	7.3
tennis ball	6.9
golf ball	4.3
marble	0.6

If Earth is a basketball, then the Moon is a:

6. Use an official basketball as a model of Earth. Use a second ball, the one you determined from Question 5, as a model of the Moon.

7. Determine the scale of your model system by setting the diameter of the basketball equal to the diameter of Earth.

_________ cm = ______________________ km therefore,

1 cm = ☐ km

8. If the distance to the Moon from Earth is 382,500 km, then how far apart must you separate the two scale models to accurately depict the Earth/Moon system?

Using the scale value in the box from Step 7, the model separation in centimeters (**x**) is derived:

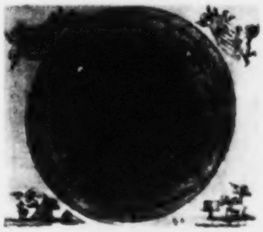
$$\mathbf{x} = \frac{\text{actual distance to the Moon in kilometers}}{\text{scale value in kilometers}}$$

$$x = \frac{\boxed{}}{\boxed{}}$$

x = _________________ centimeters

The two scale models must be separated by __________ meters.

9. Set up your scale model of the Earth/Moon system. Does it fit in your classroom?



Diameter of the Moon

Purpose

To calculate the diameter of the Moon using proportions.

Background

The diameter of the Moon is proportional to the diameter of a cardboard disk, given that you know the distance to the Moon and the distance to the cardboard disk.
The relationship is:

$$\frac{d}{l} = \frac{D}{L}$$

so that:

$$D = L(d/l)$$

where **D** = diameter of Moon
d = diameter of cardboard disk
L = distance to Moon
l = distance to cardboard disk

In this activity, students will measure **d** and **l**. They will be given **L**.
They will calculate **D.**

The diameter of the Moon (**D**) is 3,476 km.

Preparation

Review and prepare materials listed on the student sheet.
Choose a day and location for this activity which is best for viewing a full Moon.

A cardboard disk of 2 cm diameter works well. Better accuracy may be achieved by using a larger disk, thus a greater distance **l**. However, if obtaining or cutting cardboard is difficult, then this activity can also be done with dimes. A dime held out at arm's length will cover the Moon.

The distance from Earth to the Moon for a given date can be obtained by asking a local planetarium staff. Or for this activity, students may use an average value of 382,500 km.

Diameter of the Moon

In Class

If students work in pairs, then one student can use the string to measure distance from their partner's eye to the disk.

The same units do not have to be used on both sides of the equation, but **d** and **l** have to be the same units. The **D** will be the same unit as **L**.

Wrap-Up

To compute the density of the Moon use the diameter to compute volume and use the mass value of 7.35 x 10^{22} kg.

Density of the Moon is 3.34 grams/cubic cm.

Diameter of the Moon

Purpose

To calculate the diameter of the Moon using proportions.

Key Words

proportional

Materials

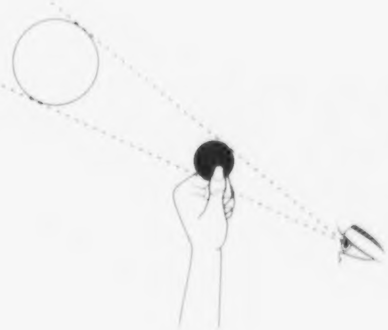
2-cm wide cardboard disk

wooden stake (optional)

meter stick

calculator

string



Procedure

1. On a day when you can see the Moon: place a **cardboard disk** on top of a **stake** or on a window sill so that it exactly covers the Moon from your point of view behind the cardboard disk.

2. Have a friend **measure the distance** from your eye to the cardboard disk.
   Call this distance **l** and write the value here:

   l = ______________________________

3. The distance from Earth to the Moon varies between 360,000 km and 405,000 km. Find the distance for today's date or use an average value for your calculations of 382,500 km.
   Write the value that you are going to use here:

   L = ______________________________

4. What is the diameter of the cardboard disk?

   d = ______________________________

5. The diameter of the Moon is proportional to the diameter of your cardboard disk by this equation:

$$\frac{d}{l} = \frac{D}{L} \qquad \text{so that, } D = L(d/l)$$

where: **D** = diameter of Moon
d = diameter of cardboard disk
L = distance to Moon
l = distance to cardboard disk

Diameter of the Moon

Results

1. By your calculations, the diameter of the Moon is:

   D = ______________________________

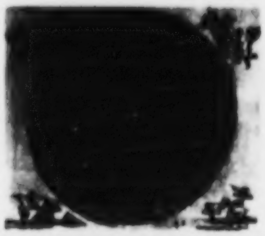
2. Compare your result with the accepted diameter of the Moon. How close did you get?

3. How many times smaller is the diameter of the Moon than the diameter of Earth?

4. When you calculated the diameter of the Moon, did you have to use the same units on both sides of the equation?

5. How and where could you find the value for the distance to the Moon for today's date?

6. What else would you need to know to compute the density of the Moon? Try it.



Reaping Rocks

Purpose

To make predictions about the origin of lunar rocks by first collecting, describing, and classifying neighborhood rocks.

Background [also see "Teacher's Guide" Pages 6, 7, photo on 14, 15]

Geologists are scientists who study the formation, structure, history, and processes (internal and on the surface) that change Earth and other planetary bodies.

Rocks and the **minerals** in them give geologists key information about the events in a planet's history. By collecting, describing and classifying rocks, we can learn how the rocks were formed and what processes have changed them.

Geologists classify rocks into three types:

Igneous - rock formed when magma cools and hardens either below the surface (for example, granite) or on the surface during volcanic events (for example, basalt).

Sedimentary - rock formed by the collection, compaction, and cementation of mineral grains, rock fragments, and sand that are moved by wind, water, or ice to the site of deposition.

Metamorphic - rock formed when heat and/or pressure deep within the planet changes the mineral composition and grain size of existing rocks. For example, metamorphism changes limestone into marble.

We find all three rock types on Earth's surface and the rocks are constantly changing (recycling), very slowly because of heat, pressure, and exposure to weather and erosion.

The Moon's surface is dominated by igneous rocks. The **lunar highlands** are formed of **anorthosite**, an igneous rock predominantly of calcium-rich **plagioclase feldspar**. The lunar **maria** are made of layers of **basaltic lava**, not unlike the basaltic flows of the Columbia River Plateau or of Iceland. The orange glass found on the Moon's surface is another product of volcanic activity. Moon rocks are not exposed to weather nor are they eroded by wind, water, or ice. The Apollo astronaut's footprints are as fresh as the day they were made.

Preparation

Review and prepare materials listed on the student sheet. Spend time familiarizing the students with rock and mineral identification.

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Reaping Rocks

Students may need more than one copy of "My Own Rock Chart" because it has spaces for only three samples. You may want to collect empty egg cartons, small boxes, or trays that the students could decorate themselves to display their rocks. Use of magnifying lenses or a stereo microscope would greatly enhance observations.

"Moon ABCs Fact Sheet" may come in handy during the wrap-up when students try to make predictions about the Moon rocks.

In Class

Talk about the qualities of rocks that we can describe: shape, size, color, texture, and the place where it was found. Then discuss the three rock classifications emphasizing that geologists classify rocks and interpret the origins of rocks based on their observations.

Encourage students to collect a variety of rocks with different colors and textures from your own locality, if possible. Remind them to choose naturally occurring materials -- not cement or brick fragments! If it is not possible to collect rocks from the neighborhood, then try to obtain a commerically available set of common rocks. More than one student may choose the same rock. Students could also cut out pictures of rocks from magazines or study pictures of rocks in text books.

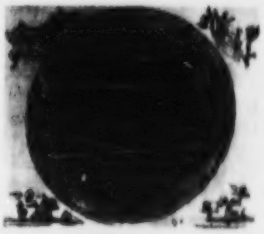
After each rock has been labeled with owner's name and location where it was found, have the students look carefully at the rock. To help them train their eyes, ask questions like: What colors do you see? Do you see grains? Are the grains large or small? Does the rock look glassy? Or does the rock show a banding pattern? Does the rock look frothy with a lot of holes? Do you see pebbles cemented together? Does the rock contain fossils?

Ask students to describe their rocks with as many adjectives or descriptive phrases as possible. Have the students classify the rocks as igneous, sedimentary, or metamorphic, and then try to interpret the rock origins. "My Own Rock Chart" is designed to help organize their observations and interpretations.

Wrap-up

Conclude the activity by challenging the students to predict what the lunar rocks look like and the possible origins based on what they have just learned about Earth rocks and based on the material in the "Moon ABCs Fact Sheet."

Display these rock collections and keep them until the students have a chance to compare with the lunar samples in "The Lunar Disk" activity on Page 39.



Reaping Rocks

Purpose

To make predictions about the origin of lunar rocks by first collecting, describing, and classifying neighborhood rocks.

Key Words

geologist

mineral

rock

igneous

sedimentary

metamorphic

Materials

rocks

empty egg carton, box, or other collection tray

labels

magnifying lens or stereo microscope

"My Own Rock Chart"

"Moon ABCs Fact Sheet"

Procedure

1. Display your **rocks** on a tray or **egg carton**, and **label** each one with the location of where you found it.
2. Look carefully at each rock with and without a **magnifying lens or stereo microscope**. What details can you see under magnification?
3. Describe what you see by filling out "**My Own Rock Chart**." Use as many adjectives or descriptive phrases as you can.
4. Classify your rocks as igneous, sedimentary or metamorphic. Try to interpret how your rocks were formed; that is, the origins. Add this information to your chart.
5. Now, based on your chart and the "**Moon ABCs** Fact Sheet," predict what the Moon rocks will look like.
6. How do you think the different Moon rocks might have formed?

My Own Rock Chart

Observations	Rock Sketch			
	Shape			
	Size			
	Colors			
	Texture			
	Collection Site			
Interpretations	Classification			
	Origin			

Unit 2

Learning from Apollo

- The Lunar Disk
- Apollo Landing Sites
- Regolith Formation
- Lunar Surface
- Differentiation
- Impact Craters
- Clay Lava Flows
- Lava Layering
- Lunar Landing Sites
- Lunar Roving Vehicle
- Moon Anomalies

The U.S. Space Program called Apollo achieved monumental goals including the collection and return of rock and sediment samples from the Moon. Analyses of the samples by scientists worldwide continue to give us new insight to the forces that shaped the early solar system, the Moon, and maybe most importantly, Earth. This excitement of discovery, a legacy of the Apollo program, is the theme of Unit 2.

The highlight of this unit is the Lunar Sample Disk. Classroom activities focus on the Moon's rocks, surface features, and the geologic processes that formed them. Students are then given the opportunity to plan their own lunar missions in the "Lunar Landing Sites" and "Lunar Roving Vehicle" activities. The last activity of the unit presents four anomalies of the Moon for investigation and interpretation.

A Resource Section for Unit 2 is on Page 38.

Resource Section

This list presents possible independent and commercial sources of items to complement the activities in Unit 2. The sources are offered without recommendation or endorsement by NASA. Materials from the U.S. Government Printing Office also are included. Inquiries should be made directly to the appropriate source to determine availability, cost, and ordering information before sending money. Contact your NASA Teacher Resource Center (see pages 147-148) for more lists of resources available directly from the National Aeronautics and Space Administration.

Books

Apollo Over the Moon: A View From Orbit, NASA SP-362, 1978, 255 p. Annotated picture book of lunar geologic features.
U.S. Government Printing Office
Superintendent of Documents
P.O. Box 371954
Pittsburgh, PA 15250-7054
1-202-783-3238

Apollo Expeditions to the Moon, NASA SP-250, 1975, 313 p. Illustrated chronicle of the Apollo missions with a focus on the engineering and teamwork that made the missions possible.
U.S. Government Printing Office, same as above

The Moon, by Patrick Moore, 1981, Rand McNally and Co., 96 p. Illustrated with maps, drawings, and Apollo mission photographs. Also gives descriptions of unmanned missions including Russian Luna probes.

To Rise From Earth: An Easy to Understand Guide to Space Flight, by Wayne Lee, 1993, Texas Space Grant Consortium (ISBN 0-9637400-3-2), 279 p. Detailed, non-mathematical discussions of orbital mechanics, Apollo missions, and the Shuttle program.

To A Rocky Moon: A Geologist's History of Lunar Exploration, by Don E. Wilhelms, 1993, Univ. of Arizona Press, 477 p.

Carrying the Fire: An Astronaut's Journeys, by Michael Collins, 1974, Ballantine Books, 488 p.

Apollo and the Moon Landing, by Gregory Vogt, 1991, Millbrook Press, 112 p. An illustrated text in the Missions in Space Series for grades 4-6.

Slides

The Apollo Landing Sites, set of 40 slides
Lunar and Planetary Institute
3600 Bay Area Boulevard
Houston, TX 77058-1113
1-713-486-2172 or
FAX 1-713-486-2186

Videos

Out of This World: The Apollo Moon Landings, Finley-Holiday Film Corp./Steve Skootsky, 1993, 60 minutes. Historically accurate video using newly restored NASA footage.
Finley-Holiday Film Corp.
P.O. Box 619
Whittier, CA 90608
1-800-345-6707

Rockets and Models

Estes Industries
P.O. Box 227
Penrose, CO 81240

Rockets: Physical Science Teacher's Guide with Activities by Gregory L. Vogt, 1993, NASA EP-291, 44 pages.

The Lunar Disk

Purpose

To carefully look at, describe, and learn about the origins of the six lunar samples contained in the disk.

Background [also see "Teacher's Guide" Pages 1, 4-9, photo on 14, 15 and "About the Lunar Sample Disk" on Page iv]

The six **Apollo** missions that landed **astronauts** on the Moon returned a collection of **rocks** and **sediment** samples weighing 382 kilograms and consisting of more than 2,000 separate samples.

Each lunar disk contains six small samples of lunar material. Descriptions of the samples accompany every disk; included are annotated color photographs, discussion of origins, and Apollo missions and collection sites.

Preparation

First, do the "Reaping Rocks" activity on Page 33 or spend time on a basic unit on rock and mineral identification.
Read the rock descriptions provided with the Lunar Sample Disk.
Review and prepare materials listed on the student sheet.
Each student will need two copies of the "Lunar Disk Sample Chart," there is room for three samples per page. Use of magnifying lenses or a stereo microscope would greatly enhance observations.

Have on hand the students' "My Own Rock Charts" for comparisons to the lunar samples. You may also want to collect some sediment from the school yard to display on a glass slide. Students could then compare this sediment to the lunar samples. Most likely, evidence of life will be seen in the school yard sediment under magnification, including plant matter, bits of plastic, fibers, etc.

In Class

The Lunar Sample Disk is a national treasure and students need to be reminded about the proper way to handle it. The disk must be in your sight during use.

Encourage students to describe the samples with as many adjectives or descriptive phrases as possible. The "Lunar Disk Sample Chart" will help students organize their observations and interpretations.

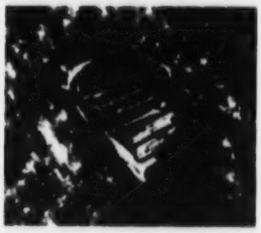
The Lunar Disk

Note: The name of each sample is labeled on the disk and may be entered on the chart under *classification*. The sediment samples, instead of being labeled regolith, are labeled "soil." Remined the students this is a misnomer because there are no organic materials in lunar regolith.

Ask the students if their predictions of the Moon rocks were accurate.

Wrap-Up

By comparing the lunar samples with their own rock collections, students can discuss the similarities and differences between Earth and Moon rocks. Discuss the various ways that rocks are formed on Earth and the Moon.



The Lunar Disk

Purpose

To carefully look at, describe, and learn about the origins of the six lunar samples contained in the disk.

Key Words

anorthosite

mare basalt

orange "soil"

breccia

mare "soil"

highland "soil"

Materials

Lunar Disk

magnifying lens or stereo microscope

"Lunar Disk Sample Chart"

"My Own Rock Chart"

"Moon ABCs Fact Sheet"

Caution

The only way to handle the Lunar Sample Disk is with care.

Always place it on the soft cloth to prevent scratchs to the surface. The disk must always be in the teacher's sight.

Care for and enjoy this national treasure.

Procedure

1. Look at each **lunar sample** with and without a **magnifying lens or stereo microscope**. What details can you see under magnification?

2. Describe what you see by filling out the "**Lunar Disk Sample Chart**." Use as many adjectives or descriptive phrases as you can.

3. Do the Moon rocks look like what you expected?

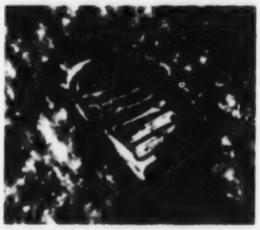
4. Which lunar samples closely resemble rocks from your collection?

5. Based on your comparisons of Earth and Moon rocks, what can you now say about the origins of the lunar samples contained in the disk? Add this information to your chart.

6. Which rock types on Earth are not found in the lunar samples? Why?

Lunar Disk Sample Chart

Observations	Sketch of Sample			
	Shape			
	Size			
	Colors			
	Texture			
	Apollo Mission/ Collection Site			
Interpretations	Classification			
	Origin			



Apollo Landing Sites

Purpose

To learn about the locations and geology of the six Apollo landing sites.

Background

Latitude and **longitude** coordinates for the Moon start at a point near the crater Bruce. From this starting point (0° latitude, 0° longitude) locations towards the east side of the Moon (the direction in which the sun rises) are indicated with east longitude values. Locations towards the west side (the direction in which the sun sets) have west longitude values. North latitude is measured towards the Moon's north pole. South latitude is measured towards the Moon's south pole.

Twelve **astronauts** in six **Apollo** missions landed on and explored the **nearside** (Earth-facing side) of the Moon between 1969 and 1972. The six landing sites were chosen to explore different geologic **terrains**.

Refer to the rock descriptions included with the Lunar Sample Disk for details on where the samples came from and who collected them. An answer chart is provided.

Preparation

Review and prepare materials listed on the student sheet.
See the Resource Section on Page 24 for sources of maps and globes.

In Class

Refer back to the Lunar Sample Disk to review the collection sites of each sample. Ask students to consider the geologic differences of the six sites.

Wrap-up

Were the Apollo landing sites in similar terrains? Which crew was the first to work in hilly terrain?

Extensions

1. Form cooperative teams to research each Apollo landing site (the who, what, when, where, and why) and to report to the class.
2. Why were all six Apollo landing sites on the nearside of the Moon?
3. Why were there no further Apollo Moon landings?
4. Was Apollo the only program to land on the Moon? Discuss the unmanned American and Soviet missions and landings.

Apollo Landing Sites Chart

Apollo Mission	Landing Date	Longitude	Latitude	Major Geologic Features and Rock Types (rock types underlined are found in the Lunar Sample Disk)
11	July 20, 1969	23 °E	1 °N	Mare (Sea of Tranquillity), basaltic lava.
12	Nov. 19, 1969	23 °W	3 °S	Mare (Ocean of Storms), rocks are basaltic lava; ray from Copernicus Crater crosses the site.
14	Jan. 31, 1971	17 °W	3 °S	Highlands (Fra Mauro formation) - thought to be ejecta from the Imbrium Basin.
15	July 30, 1971	4 °E	26 °N	Mare (Hadley Rille in a mare area near the margin of Mare Imbrium) and highlands (Apennine Mountains, a ring of the Imbrium basin); rocks are breccia and basalt.
16	April 21, 1972	16 °E	9 °S	Highlands (Descartes formation and Cayley Plains); rocks are anorthosite and highlands soil.
17	Dec. 11, 1972	31 °E	20 °N	Mare (Sea of Serenity) and Highlands; rocks are mare soil, orange soil, basaltic lava, anorthosite.

Apollo Landing Sites

Purpose

To learn about the locations and geology of the six Apollo landing sites.

Key Words

latitude

longitude

mare

highlands

Sea of Tranquillity

Ocean of Storms

Fra Mauro

Hadley-Appenine

Descartes

Sea of Serenity

Taurus-Littrow

Materials

lunar maps with latitude and longitude grid

"Apollo Landing Sites Chart"

Moon globe

Procedure

1. Look at a **map** of the Moon showing the Apollo landing sites. Fill in the **"Apollo Landing Sites Chart."**

2. Find the landing sites on a **globe** of the Moon.

3. How do **latitude** and **longitude** compare on Earth and on the Moon?

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4. Compare and contrast the six Apollo landing sites. (Think about who, when, where, and geology for your answer.)

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5. Which site would you most like to visit? Why?

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Apollo Landing Sites Chart

Apollo Mission	Landing Date	Longitude	Latitude	Major Geologic Features and Rock Types

Regolith Formation

Purpose

To compare the process of regolith formation on Earth and on the Moon.

Background [also see "Teacher's Guide" Pages 4, 5]

The loose, fragmental material on the Moon's surface is called **regolith**. This regolith, a product of **meteoritic bombardment**, is the debris thrown out of the **impact craters**. The composition and texture of the lunar regolith varies from place to place depending on the **rock** types impacted.

Generally, the older the surface, the thicker the regolith. The regolith on young **maria** may be only 2 meters thick; whereas, it is perhaps 20 meters thick in the older lunar **highlands**.

By contrast, regolith on Earth is a product of **weathering**. Weathering encompasses all the processes that cause rocks to fragment, crack, crumble, or decay. These processes can be *physical* (such as freezing water causing rocks to crack), *chemical* (such as decaying of minerals in water or acids), and *biological* (such as plant roots widening cracks in rocks).

The rock debris caused by weathering can then be loosened and carried away by **erosional** agents -- *running water* (fast-flowing rivers, rain, ocean waves), *high-speed wind* (by itself or sandblasting), and *ice* (glaciers).

In this activity, procedures A and B challenge the students to determine the effects of wind, sandblasting, and water on regolith formation and deposition on Earth. This is followed by prodedure C in which the students simulate regolith formation on the Moon by meteoritic bombardment.

Preparation

Review and prepare materials listed on the student sheet.
Toast, crackers, or brittle cookies can be used in this activity. Toast is the least expensive but most time consuming choice. In any case, students will need two different colors of materials for procedure C; for example, vanilla and chocolate graham crackers. Invariably, students get hungry at the sight of food, so you may want to reserve some clean materials for consumption or use something other than a rock for the projectile.
To prepare bread: use a conventional oven, toaster, or sun-dry method to produce the most crisp and brittle toast. Toast one loaf of white bread and one loaf of golden wheat or rye bread. Note that whole wheat bread does not get brittle enough.

For procedure B, fill margarine containers (one for each group) with water and sand, then freeze. The more sand, the better the illusion to a real rock.

For procedure C, do not use glass pans. Large plastic tubs are preferred for this procedure, but recyclable aluminum roasting pans or shallow cardboard boxes work as well.

In Class

Divide the students into cooperative groups and distribute materials.

Discuss the definition of regolith. Have students guess how regolith is formed on Earth and on the Moon. Ask students for justification.

If sand paper or nail files are not available, then students can use the edge of a ruler to illustrate the effects of sandblasting in procedure A. Caution students to use a collection tray in the sink in procedure B to avoid sand-clogged drains. An alternative to using a faucet is to have the students pour a steady stream of water from beakers onto their ice-cube rocks to illustrate the effects of falling water.

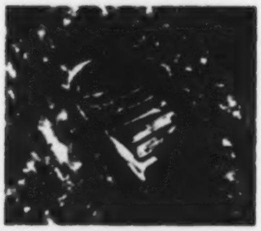
Have students guess individually, then discuss in groups, what the surface of the Moon is like (hard rocks, fine dust, large boulders). Ask students for justification of their answers.

Refer to a photograph of an astronaut's bootprint on the surface of the Moon. Give students the opportunity to change or confirm their guesses.

Procedure C is best done outside. Drop the rock from waist high. Sometimes the impacting rock causes the pan to bounce so you may want to secure the pan to the ground with tape. Students should stand back as a safety precaution.

Wrap-up

After participating in the activity, have the whole class compare and contrast regolith formation and ask each small group to verify their original guesses.



Regolith Formation

Purpose

To compare and contrast the process of regolith formation on Earth and on the Moon.

Key Words

regolith

meteoritic bombardment

weathering

erosion

Materials

toasted white bread

toasted golden wheat bread

small pan

sand paper, nail file, or edge of ruler

ice cube with sand inside

tray

fist-size rock

Regolith formation on Earth

Procedure A

What effect does wind have on regolith formation?

1. Imagine that the piece of toasted bread is a rock on Earth. Your hand is the wind. The sand paper is wind carrying particles of sand.

2. Predict the effects of rubbing just your hand and then the sand paper across the toasted bread.

3. Now try it. Rub your hand across the **toasted bread** and observe the bread and the pieces which fall from it onto the **pan**. Observations:

4. This time rub the **sand paper** across the toasted bread and observe the bread and the pieces which fall from it onto the pan. Observations:

5. How was the effect different?

6. How is this activity related to processes on Earth?

Procedure B

What effect does falling or fast flowing water have on regolith formation?

1. Imagine that the **ice cube with sand** is a rock.
2. Place this ice cube on a collection tray beneath the **water faucet**.
3. Adjust the water flow from the faucet so a medium stream hits the ice cube.
4. Observe what happens to the ice cube and the remaining particles.
5. What happened to the rock (ice cube)?

6. Describe the particles which remain.

7. How does water contribute to regolith formation on Earth?

Regolith formation on the Moon

Procedure C

1. Do you think regolith on the Moon is formed in the same manner as on Earth? Why or why not?

Now we will investigate the effects of meteoritic bombardment on regolith formation.

2. In a small **pan**, place 2 slices of **toasted white bread** onto 3 slices of **toasted golden wheat bread**. This represents the Moon's crust.

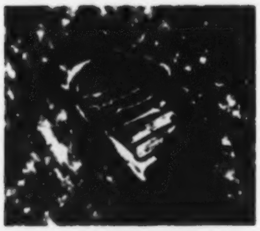
3. Drop a **rock** onto the layers of toasted bread twice. Describe the bread slices and the crumbs.

4. Drop the rock 20 times onto the layers of toasted bread. Describe the bread slices and the crumbs.

5. Which crumbs can be seen at the surface? Why?

6. How does the thickness of the crumb layers compare after 2 hits and after 20 more hits?

7. How does meteoritic bombardment make regolith on the Moon?



Lunar Surface

Purpose

To make a model of the Moon's surface and to consider the geologic processes and rocks of each area.

Background [also see "Teacher's Guide" Pages 2, 3, 4, 12, 13]

A variety of features are evident on the lunar surface. These features include **craters** with and without **rays** (also see the "Impact Craters" activity on Page 61), **crater chains**, **maria**, **rilles**, and **mountains**.

crater chains - in curved paths are probably incompletely formed rilles,

- in straight paths are probably from rocks thrown out during an impact event and landing in a row.

rilles - are long valleys crossing maria that formed as underground lava channels which collapsed after the hot lava flowed away.

mountains - almost all in the highlands are the rims of large craters,

- also occur in the centers of craters that are larger than 40 km diameter; these mountains are called central uplifts,

- also occur as low, circular, rounded hills called domes.

In this activity students will use clay, plaster of Paris, or playdough to construct model surfaces to match what they see on maps and photographs of the Moon. They "flag" Apollo landing sites and consider the collection site of each Lunar Disk sample.

Preparation

Review and prepare materials listed on the student sheet.
Obtain one or more lunar maps. Students can either be assigned to or given a choice of specific areas to model. Using maps of both the nearside (Earth-facing side) and farside of the Moon will give more variety of surface features.

Collect trays or shallow cardboard boxes and modeling material (recipes for playdough appear on Page 78). Assemble sculpturing tools such as wooden sticks, plastic knives, rolling pins, etc.

Lunar Surface

It is beneficial to do "The Lunar Disk" activity (on Page 39) first so students can relate the samples to their model surfaces.

In Class

Consider having cooperative teams build one model surface. Each team is responsible for describing the surface features, explaining the geology, and listing the typical rock types of the area. Either draw an outline around each area on a Moon map or if you have an extra map, cut the map into sections. The whole map is finally recreated by putting the model surfaces back together.

Have the students use toothpick flags to label Apollo landing sites.

Wrap-up

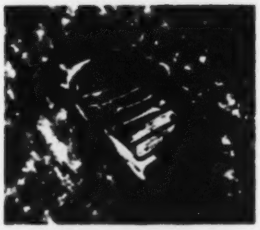
Review the variety of surface features found on the Moon. Are some features more common than others?

What are the most common terrains on the Moon? Do these terrains exist on the nearside, farside, or globally?

Review the processes that made the various surface features. Also see the "Impact Craters" activity on Page 61 and the "Clay Lava Flows" activity on page 71.

What kinds of rocks are found in the areas modeled by the students? Also see the "Apollo Landing Sites" activity on page 43 and the literature which accompanies the Lunar Sample Disk.

If the student teams made models of different sections of a large map, then did the modeled surface features match from tray to adjacent tray? Have the students discuss why or why not.



Lunar Surface

Purpose

To make a model of the Moon's surface and to consider the geologic processes and rocks of each area.

Key Words

crater
mountain
rille
mare
crater chain
ray
terrain

Materials

binoculars or telescope
lunar map
photographs of the Moon
clay, plaster of Paris, or playdough
tray
sculpturing tools
toothpick flags
Lunar Sample Disk

Procedure

1. Observe the Moon using **binoculars** or a **telescope**. What surface features can you see?

2. Look at a **map** and **photographs** of the Moon. List the many different features you see.

3. Prepare a model lunar surface by placing a thin, even layer of **modeling material** on a **tray**.

4. Use **sculpturing tools** to form the features that you see on the Moon's surface.

5. How do you think these surface features were created on the Moon? List at least one idea for each kind of feature.

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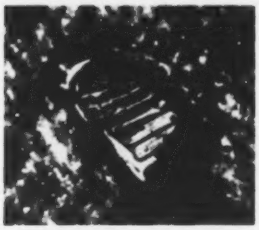
6. If your model surface has an Apollo landing site, then label it with a **toothpick flag**.

7. What kinds of rocks occur in your area? If your area has an Apollo landing site, then include the names of samples from the **Lunar Sample Disk** in your answer.

8. Compare your model surface with your classmates' surfaces. Can you match features from one area to another? Why or why not?



Differentiation

Purpose

To see how minerals separate from each other in a magma ocean.

Background [also see "Teacher's Guide" Page 12]

When planets begin to melt, the materials in them begin to separate from one another. The heaviest materials, such as metallic iron, sink to form **cores**. Low density magmas rise forming **crusts**. This process is called **differentiation**.

Soon after formation, the Moon melted substantially forming a large body of **magma** that completely surrounded it. This is called the **lunar magma ocean**. The main evidence that this actually happened on the Moon is the presence of large amounts of the **mineral plagioclase feldspar** in the ancient, lunar **highlands** crust. Scientists surmise feldspar floated in the magma ocean and accumulated at the top, while denser minerals such as olivine and pyroxene sank and accumulated at the base of the magma ocean.

This same process happens in lava lakes and in magma chambers beneath **volcanoes** on Earth. Minerals denser than the melt sink; those less dense float. It is an important geological process that leads to the production of a wide variety of **igneous rocks**.

Preparation

Review and prepare materials listed on the student sheet. Students will simulate the process of differentiation using readily-available materials: water, a transparent container (1000-milliliter beakers are good because they look scientific, but any wide-mouthed glass will work), pennies or metal shot, sand, and toothpicks.

In Class

Take a handful of pennies, sand, and toothpicks and dump them into the water. The pennies (or metal shot) sink faster than the sand. The toothpicks float. The floating toothpicks lie at a variety of angles and are analogous to the feldspar that formed the initial lunar crust. There ought to be more pennies than sand on the very bottom, with sand on top of that pile. (The pennies are much denser, 8.9 grams per cubic centimeter, than the sand, about 2.6 grams per cubic centimeter, so the pennies sink faster.) The clear water in between represents still-molten magma.

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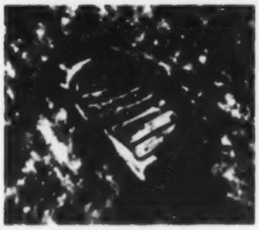
Differentiation

This activity can be done as a demonstration if you prefer.

Wrap-up

Relate the sinking and floating objects to the differentiation of the Moon's magma ocean.



Differentiation

Purpose

To see how minerals separate from each other in a magma ocean.

Key Words

differentiation

density

magma ocean

Materials

pennies

sand

toothpicks

bowl

transparent container

water

Procedure

1. Mix the **pennies, sand, and toothpicks** in the **bowl**.

2. Fill the **container** with **water** to about 2 cm from the top.

3. Predict what will happen when you drop a handful of the pennies-sand-toothpicks mixture into the water. Will they all sink to the bottom? Will some sink faster than others?

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4. Now drop the mixture into the water. Wait until the objects stop moving and look at the deposits. What do you see?

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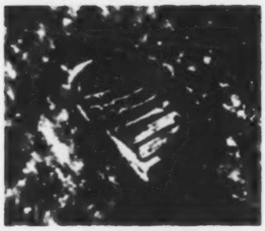
5. Can you explain what causes the differences in the way the objects sink or float?

6. Suppose the mineral feldspar in the lunar magma ocean responded like the toothpicks in the water. What does this tell you about the formation of the original crust on the Moon?

7. What makes up the highlands of the Moon? Based on this experiment, does this make sense?



Impact Craters

Purpose

To determine the factors affecting the appearance of impact craters and ejecta.

Background [also see "Teacher's Guide" Pages 1, 2, photo on 8, 12, and photo on 13]

The circular features so obvious on the Moon's surface are **impact craters** formed when **impactors** smashed into the surface. The explosion and excavation of materials at the impacted site created piles of rock (called **ejecta**) around the circular hole as well as bright streaks of target material (called **rays**) thrown for great distances.

Two basic methods that form craters in nature are:
1) impact of a **projectile** on the surface and 2) collapse of the top of a **volcano** creating a crater termed *caldera.* By studying all types of craters on Earth and by creating impact craters in experimental laboratories geologists concluded that the Moon's craters are impact in origin.

The factors affecting the appearance of impact craters and ejecta are the size and velocity of the impactor, and the geology of the target surface.

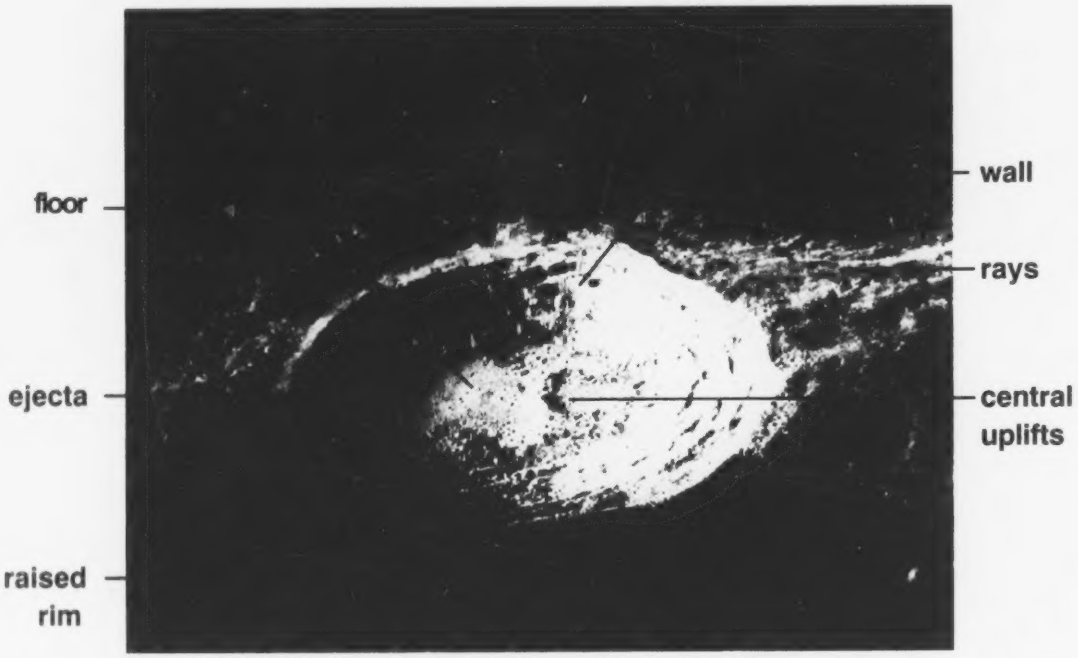
By recording the number, size, and extent of erosion of craters, **lunar geologists** can determine the ages of different surface units on the Moon and can piece together the geologic history. This technique works because older surfaces are exposed to impacting **meteorites** for a longer period of time than are younger surfaces.

Impact craters are not unique to the Moon. They are found on all the terrestrial planets and on many moons of the outer planets.

On Earth, impact craters are not as easily recognized because of weathering and erosion. Famous impact craters on Earth are Meteor Crater in Arizona, U.S.A.; Manicouagan in Quebec, Canada; Sudbury in Ontario, Canada; Ries Crater in Germany, and Chicxulub on the Yucatan coast in Mexico. Chicxulub is considered by most scientists as the source crater of the catastrophe that led to the extinction of the dinosaurs at the end of the Cretaceous period. An interesting fact about the Chicxulub crater is that you cannot see it. Its circular structure is nearly a kilometer below the surface and was originally identified from magnetic and gravity data.

Aristarchus

Typical characteristics of a lunar impact crater are labeled on this photograph of Aristarchus, 42 km in diameter, located West of Mare Imbrium.



raised rim	- rock thrown out of the crater and deposited as a ring-shaped pile of debris at the crater's edge during the explosion and excavcation of an impact event.
floor	- bowl shaped or flat, characteristically below surrounding ground level unless filled in with lava.
central uplifts	- mountains formed because of the huge increase and rapid decrease in pressure during the impact event. They occur only in the center of craters that are larger than 40 km diameter. See Tycho crater for another example.
walls	- characteristically steep and may have giant stairs called terraces.
ejecta	- blanket of material surrounding the crater that was excavated during the impact event. Ejecta becomes thinner away from the crater.
rays	- bright streaks starting from a crater and extending away for great distances. See Copernicus crater for another example.

Impact Craters

Preparation

Review and prepare materials listed on the student sheet.
In this activity, marbles or other spheres such as steel shot, ball bearings, or golf balls are used as impactors that students drop from a series of heights onto a prepared "lunar surface." Using impactors of different mass dropped from the same height will allow students to study the relationship of mass of the impactor to crater size. Dropping impactors from different heights will allow students to study the realtionship of velocity of the impactor to crater size.

The following materials work well as a base for the "lunar surface" topped with a dusting of dry tempera paint or other material in a contrasting color:

all purpose flour - Reusable in this activity and keeps well in a covered container.

baking soda - It can be recycled for use in the lava layer activity or for many other science activities. Reusable in this activity, even if colored, by adding a clean layer of new white baking soda on top. Keeps indefinitely in a covered container. Baking soda mixed (1:1) with table salt also works.

corn meal - Reusable in this activity but probably not recyclable. Keeps only in freezer in airtight container.

sand and corn starch - Mixed (1:1), sand must be very dry. Keeps only in freezer in airtight container.

dry tempera paint or powdered drink mixes or glitter - Sift on top; use a sieve, screen, or flour sifter. A contrasting color to the base materials gives striking results.

Pans should be plastic, aluminum, or cardboard. Do not use glass. They should be at least 7.5 cm deep. Basic 10"x12" aluminum pans or plastic tubs work fine, but the larger the better to avoid misses. Also, a larger pan may allow students to drop more marbles before having to resurface the target materials.

A reproducible student "Data Chart" is included; students will need a separate chart for each impactor used in the activity.

Impact Craters

In Class

1. Begin by looking at craters in photographs of the Moon and asking students their ideas of how craters formed.

2. During this activity, the flour, baking soda, or dry paint may fall onto the floor and the baking soda may even be disbursed into the air. Spread newspapers under the pan(s) to catch spills or consider doing the activity outside. Under supervision, students have successfully dropped marbles from second-story balconies. Resurface the pan before a high drop.

3. Have the students agree beforehand on the method they will use to "smooth" and resurface the material in the pan between impacts. The material need not be packed down. Shaking or tilting the pan back and forth produces a smooth surface. Then be sure to reapply a fresh dusting of dry tempera paint or other material. Remind students that better experimental control is achieved with consistent handling of the materials. For instance, cratering results may vary if the material is packed down for some trials and not for others.

4. Allow some practice time for dropping marbles and resurfacing the materials in the pan before actually recording data.

5. Because of the low velocity of the marbles compared with the velocity of real impactors, the experimental impact craters may not have raised rims. Central uplifts and terraced walls will be absent.

6. The last drop height should be as high and safe as practical.

7. The higher the drop height, the greater the velocity of the marble, so a larger crater will be made and the ejecta will spread out farther.

8. If the impactor were dropped from 3 times the maximum drop height, then the crater would be larger. The students need to extrapolate the graph out to 3 times the maximum height and read the predicted crater diameter.

Wrap-Up

Have the class compare and contrast their hypotheses on what things affect the appearance of craters and ejecta.

Extensions

1. As a grand finale for your students, demonstrate a more forceful impact using a slingshot.

2. What would happen if you change the angle of impact? How could this be tested? Try it! Do the results support your hypothesis?

   If the angle of impact is changed, then the rays will be concentrated and longer in the direction of impact. A more horizontal impact angle produces a more skewed crater shape.

3. To focus attention on the rays produced during an impact, place a paper bulls-eye target with a central hole on top of a large, flour-filled pan. Students drop a marble through the hole to measure ray lengths and orientations.

4. Use plaster of Paris or wet sand instead of dry materials.

5. Videotape the activity.

6. Some people think the extinction of the dinosaurs was caused by massive global climate changes because of a meteorite impact on Earth. Summarize the exciting work that has been done at Chicxulub on the Yucatan coast of Mexico.

7. Some people think Earth was hit by an object the size of Mars that caused a large part of Earth to "splash" into space, forming the Moon. Do you agree or disagree? Explain your answer.

impactor # ☐

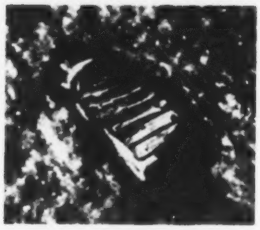
☐ gm

Name: ______________________________

Date: ____________________

Impact Craters - Data Chart

		trial 1	trial 2	trial 3	total	average
drop height = 30 cm	crater diameter					
	crater depth					
	average length of all rays					
drop height = 60 cm	crater diameter					
	crater depth					
	average length of all rays					
drop height = 90 cm	crater diameter					
	crater depth					
	average length of all rays					
drop height =	crater diameter					
	crater depth					
	average length of all rays					



Impact Craters

Purpose

To determine the factors affecting the appearance of impact craters and ejecta.

Key Words

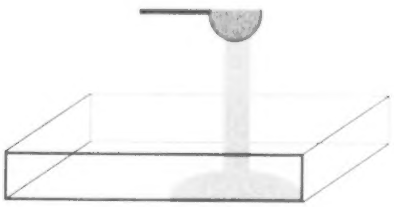
impact

impactor

ejecta

Materials

- 1 pan
- "lunar" surface material
- tempera paint, dry
- sieve or sifter
- balance
- 3 impactors (marbles or other spheres)
- meter stick
- ruler, plastic with middle depression
- protractor
- "Data Chart"
- graph paper



Procedure

Making an hypothesis

1. After looking at photographs of the Moon, how do you think the craters were formed?

2. What do you think are factors that affect the appearance of craters and ejecta?

Preparing a "lunar" test surface

1. Fill a **pan** with **surface material** to a depth of about 2.5 cm. Smooth the surface, then tap the pan to make the materials settle evenly.

2. Sprinkle a fine layer of **dry tempera paint** evenly and completely over the surface. Use a **sieve** or **sifter** for more uniform layering.

3. What does this "lunar" surface look like before testing?

Cratering Process

1. Use the **balance** to measure the mass of each **impactor**.
2. Drop impactor #1 from a height of 30 cm onto the prepared surface.
3. **Measure** the diameter and depth of the resulting crater.
4. Note the presence of ejecta (rays). Count the rays, measure, and determine the average length of all the rays.
5. Record measurements and any other observations you have about the appearance of the crater on the "**Data Chart.**" Make three trials.
6. Repeat steps 2 through 5 for impactors #2 and #3.
7. Now repeat steps 2 through 6, dropping the three impactors from heights of 60 cm, 90 cm, and from your classroom limit (just how high can you reach?)
8. Complete the "Data Chart."
9. Graph your results.
   Graph #1: Average crater diameter vs. impactor height.
   Graph #2: Average ejecta length vs. impactor height.

Results

1. Is your hypothesis supported by test data? Explain why or why not.

80

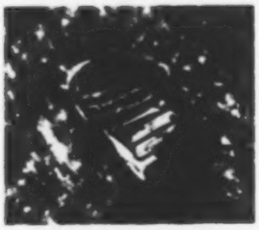
2. What do the data reveal about the relationship between crater size and velocity of impactor? Does a crater size limit exist? Explain your answer.

3. What do the data reveal about the relationship between ejecta length and velocity of impactor? Does a length limit exist? Explain your answer.

4. If the impactor were dropped from 3 times your maximum drop height, would the crater be larger or smaller? How much larger or smaller? Explain your answer.

5. Based on the experimental data, describe the appearance of an impact crater.

6. Compare your description with your classmates' descriptions. Make a group decision on the characteristics of impact craters and use these characteristics to identify impact craters on the Moon.



Clay Lava Flows

Purpose

To understand some of the geological processes and the structures that form as lava flows across planetary landscapes by using mud as an analog for lava.

Background [also see "Teacher's Guide" Pages 3, 4, 12, 13]

In this activity students will use mud to simulate surface **lava** flows. The experiment demonstrates many of the key features of **a'a** flows, though not of whole **pahoehoe** flow fields, which are fed by lava tubes.

Real a'a lava flows are complicated. They are characterized by a prominent lava **channel** confined between levees. Shear zones, places where one portion of the flow is moving faster than an adjacent portion, usually occur. Small flows of pahoehoe lava also become channelized, but on a much smaller scale than a'a flows.

As mud is poured onto an inclined surface, the first and foremost thing to do is to observe the formation of distinct features in the flow. **Levees** form on the outer part of the flow. These are not quite the same as levees on lava flows because the latter build up levees by overflowing the banks, but nevertheless, mud flows do form levees. Inside the levees the mud moves downhill. **Ridges** might develop in the flowing portions, analogous to large ridges in lava flows. The thickness of the flow varies with slope, time, position in the flow, and amount of mud poured. These variables can be tested by measuring width and thickness as functions of time, as described in the procedure.

Preparation

Review and prepare materials listed on the student sheet.
Mix clay and water in a bucket: 5 pounds of wet clay with 4 cups of water. To mix easily, break clay into half-inch pieces and allow to dry. The mixing process should be started at least 2 days before you intend to use the clay. Cover the bucket to keep the clay mixture from hardening.

The final clay-water mixture should be fairly uniform, with only a few lumps. Smooth the mixture with a wire whisk to the consistency of thick cream. If the mixture is too runny, then it will pour like water. If it is too thick, then it will mound up (though that is interesting and somewhat resembles some very viscous lava flows).

Plexiglas is an excellent surface to use for the experiment, though any nonporous surface will do fine, such as a wooden drawing board covered with plastic wrap. If the surface is too porous, then the mud loses moisture to it, changing flow characteristics.

Clay Lava Flows

Draw a grid with 10 cm spacing onto the Plexiglas using a permanent marker pen. Or draw a grid onto paper taped to the wooden board, then cover with plastic wrap.

In Class

Using a protractor and plumb line, the Plexiglas is propped up to an angle of 15° for the procedure, then to an angle of 25° for a repeat of the procedure.

Students should pour the clay slowly and at a constant rate down the inclined Plexiglas. The bucket should be held about 10 cm from the high end of the Plexiglas.

At each 10 cm mark, the students will:

1. record the time the flow front passes the mark,

2. measure the length of the flow,

3. measure the width of the flow,

4. measure the center depth of the flow.

"Data Tables" are provided for recording these values. Space is provided for sketches of the flow outline.

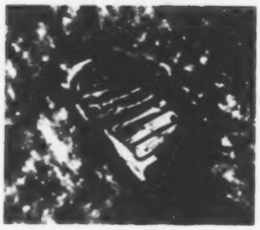
When the clay is flowing down the Plexiglas, look for areas near the edges where the flow rate is low or zero; these are the levees of the channel. The part in the middle that is moving faster is called the channel interior.

Wrap-up

How do the two flows compare?
Is the ratio of channel width to flow width the same?
Presumably the clay volumes were the same for both slopes, but the flow areas could be determined and multiplied by the average depths as an exercise just to check.

Extensions

1. Use a ruler with a grid to slice into the flow at each 10 cm mark to get cross sections.
2. Can you see the levee margins in the cross sections?
3. How do the cross sections change down the length of the flow?
4. Videotape the activity.
5. Use this clay in the "Impact Craters" activity on Page 61.



Clay Lava Flows

Purpose

To understand some of the geological processes and the structures that form as lava flows across planetary landscapes by using mud as an analog for lava.

Key Words

lava flows

channels and levees

pressure ridges

Materials

clay mixture

bucket, preferably with pouring spout

wire whisk

large spatula

Plexiglas or other nonporous surface (~1/2 by 1 meter, and preferably with a grid)

protractor with plumb line

stopwatch

"DataTables"

tape measure or ruler

Procedure

1. Stir your mixture of **clay** and **water** in the **bucket**. A few lumps are acceptable.

2. Prop up one end of the **Plexiglas** at an angle of about 15° (use the **protractor** and **plumb line** to determine the angle). A board under the Plexiglas helps prevent sagging.

3. Hold the bucket of clay mixture about 10 cm downslope from the high end of the Plexiglas. Keep the bucket about 10 cm above the Plexiglas surface. Pour the clay slowly. It is important to keep the pour rate as constant as possible. Start the **stopwatch** when the flow front passes the zero line.

4. Watch the flow as it goes downhill and spreads out, and record the time it reaches each 10 cm mark. How far behind the flow front does the distinct channel become apparent?

5. Record the time when you stopped pouring (the flow will continue to move). Fill in the "**Data Tables**."

6. Note the channel and levees as well as shear zones within the levees. Does the channel extend the entire length of the flow?

7. Using the **tape measure**, measure the length, width, and center depth of the flow and the channel width at each 10 cm mark. Fill in the "Data Tables."

8. Draw the outline of the flow using the grid as a guide.

9. Now prop the Plexiglas up higher to an angle of about 25° and repeat the procedure. The clay may flow off the end of the ramp onto the flat underlying surface. How do the structures in this flat part compare to those on the slope?

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____

____

____

10. Repeat all the measurements and fill in the "Data Tables."

11. How do the two experimental flows compare? Is the ratio of channel width to flow width the same?

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Data Tables

Angle	Time at 0	10	20	30	40	50	60	70	80	90	Time stopped pouring
15°											
25°											

Angle	Width at 0	10	20	30	40	50	60	70	80	90	Total length
15°											
25°											

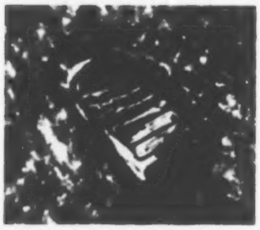
Angle	Center-line depth at 0	10	20	30	40	50	60	70	80	90
15°										
25°										

Angle	Channel width at 0	10	20	30	40	50	60	70	80	90
15°										
25°										

Clay Lava Flows

Sketch of
flow at 15°

Sketch of
flow at 25°



Lava Layering

Purpose

To learn about the stratigraphy of lava flows produced by multiple eruptions.

Background [also see “Teacher's Guide” Pages 3, 4, 12, 13]

Dark, flat **maria** (layers of **basaltic lava** flows) cover about 16 percent of the Moon’s total surface. They are easily seen on a full Moon with the naked eye on clear nights from most backyards. The maria, quite similar to Earth’s basalts, generally flowed long distances utlimately flooding low-lying areas such as **impact** basins. Yet, the **eruption sources** for most of the lunar lava flows are difficult to identify. The difficulty in finding source areas results from burial by younger flows and/or erosion from meteoritic bombardment.

Generally, the overall slope of the surface, local topographic relief (small cliffs and depressions), and eruption direction influence the path of lava flows. Detailed maps of the **geology** of the Moon from photographs reveal areas of complicated lava layering. The study of rock layering is called **stratigraphy**.

On the Moon, older flows become covered by younger flows and/or become more pocked with impact craters.

On Earth, older lava flows tend to be more weathered (broken) and may have more vegetation than younger flows. Field geologists use differences in roughness, color, and chemistry to further differentiate between lava flows. They also follow the flow margins, **channels**, and **levees** to try to trace lava flows back to the source area.

The focus of this activity is on the patterns of lava flows produced by multiple eruptions. We use a short cup to hold the baking soda because we are looking at the flows and not at constructing a volcano model. Volcanoes, like those so familiar to us on Earth and Mars, are not present on the Moon. Three well-known areas on the Moon interpreted as important volcanic complexes are: Aristarchus plateau, and the Marius Hills and Rumker Hills (both located in Oceanus Procellarum). These areas are characterized by sinuous rilles (interpreted as former lava channels and/or collapsed lava tubes) and numerous domes.

Lava Layering

Preparation

Baking soda-vinegar solutions and playdough are used to model the basaltic lavas. Different colors identify different eruption events; this activity calls for 4 colors. Students will be asked to observe where the flows traveled and to interpret the stratigraphy. Cover the work area and be prepared for spills.

Play Dough (stove-top recipe)

-best texture and lasts for months when refrigerated in an air tight container.

2 cups flour
1 cup salt
4 teaspoons cream of tarter
1/3 cup oil, scant
2 cups cold water
food colorings (20 drops more or less)

Make this large batch one color or divide ingredients in half to make 2 colors. You will need 4 colors total. Combine ingredients and cook mixture in a large sauce pan, stirring constantly, until the dough forms a ball. Turn dough out onto a floured surface to cool. Then kneed until smooth and elastic. Cool completely; refrigerate in air tight containers.

Play Dough (no-cooking recipe)

2 cups flour
1 cup salt
6 teaspoons alum or cream of tartar
2 Tablespoons oil
1 cup cold water
food colorings (as above)

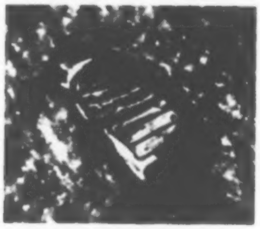
Make this large batch one color or divide ingredients in half to make 2 colors. You will need 4 colors total. Mix ingredients and kneed until smooth and elastic. Store in air tight containers.

In Class

This activity can be done individually or in cooperative teams.
Making a vertical cut through the flows reveals, quite dramatically, the stratigraphy of the section.

Wrap-up

Have students compare their layered lava patterns with their classmates' patterns. Did they recognize individual flows by color and outline? Point out how the oldest flow is on the bottom of the stack. Each succeeding flow covers older flows. The youngest flow is on top.



Lava Layering

Purpose

To learn about the stratigraphy of lava flows produced by multiple eruptions.

Key Words

eruption

source

stratigraphy

Materials

paper cups, 4 oz. size, some cut down to a height of 2.5 cm

cafeteria tray or cookie sheet, 1 for each eruption source

tape

tablespoon

baking soda

measuring cup

vinegar

food coloring, 4 colors; for example, red, yellow, blue, green

playdough or clay in the same 4 colors as the food coloring

Procedure

1. Take one **paper cup** that has been cut to a height of 2.5 cm and secure it onto the **tray**. (You may use a small loop of **tape** on the outside bottom of the cup.) This short cup is your eruption source and the tray is the original land surface.

2. Place one **Tablespoon of baking soda** in this cup.

3. Fill 4 tall paper cups each with **1/8 cup of vinegar**.

4. To each paper cup of vinegar add 3 drops of **food coloring**; make each cup a different color. Set them aside.

5. Set aside small balls of **playdough**, one of each color.

6. You are now ready to create an eruption. Pour red-colored vinegar into your source cup and watch the eruption of "lava."

7. As best you can, use red playdough to cover the areas where red "lava" flowed.

8. Repeat steps 6 and 7 for each color of vinegar and playdough. You may add fresh baking soda to the source cup or spoon out excess vinegar from the source cup as needed.

Lava Layering

Results

1. After your four eruptions, can you still see the original land surface (tray)? Where?

2. Describe what you see and include observations of flows covering or overlapping other flows. Use the left page margin to make a sketch.

3. Where is the oldest flow?

4. Where is the youngest flow?

5. Did the flows always follow the same path? (be specific)

6. What do you think influences the path direction of lava flows?

7. If you had not watched the eruptions, how would you know that there are many different layers of lava? Give at least 2 reasons:

Lava Layering

8. Which of the reasons listed in answer 7 could be used to identify real lava layers on Earth?

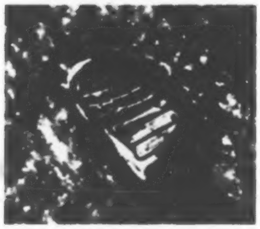
9. What are other ways to distinguish between older and younger layered lava flows on Earth?

10. Which of the reasons listed in answer 9 could be used to identify lava layers on the Moon?

11. What are other ways to distinguish between older and younger layered lava flows on the Moon?

12. Make a vertical cut through an area of overlapping playdough "lava" layers. Draw what you see in the vertical section. Color your sketch and add these labels:
oldest flow, youngest flow.

Vertical section through the flows



Lunar Landing Sites

Purpose

To design a spacecraft for travel to and from the Moon and choose an interesting lunar landing site.

Background [also see "Teacher's Guide" Pages 2-5]

The previous Unit 2 activities introduce the Moon's rocks, surface features, and the geologic processes that formed them. With this background, students are given the challenge to plan a mission to the Moon. In this activity, teams of students design a spacecraft, choose a suitable lunar landing site, and present their ideas before the entire class. Final presentations should include speeches and visual aides such as maps, diagrams, and 3-dimensional models.

Preparation

Review and prepare materials listed on the student sheet. Schedule library time as needed.

In Class

Lead a discussion on what the students need to know about the Moon in general and about potential landing sites *before* landing. A review of the Apollo sites may help initiate a discussion.

After presenting the scenario and tasks to the class, form cooperative teams of 3-4 students. Each student will have assigned duties, as described on the reproducible "Team Duty Sheet."

For the presentations, either 3-D models or poster-size diagrams can be made, depending on resources and time. Any one or all team members may participate in the presentations.

Scenario: NASA has given you the assignment to develop a spacecraft that can fly people safely to the Moon, land, and return to Earth. You must select a safe yet interesting lunar landing site for the spacecraft.

Size, mass, propulsion, number of crew, life support systems, and methods of takeoff and landing should be considered for the spacecraft. Geology, terrain, safety, and length of stay should be considered for the lunar landing site.

Lunar Landing Sites

Wrap-up

1. How do the sites chosen by the class compare in location and geologic diversity with the Apollo sites?

2. What made some spaçecraft designs and landing sites, in this activity, more risky than others?

3. Are these lunar landing sites good for short-term visits only, or could the sites be appropriate for lunar base development?
   See the "Lunar Land Use" activity on Page 101.

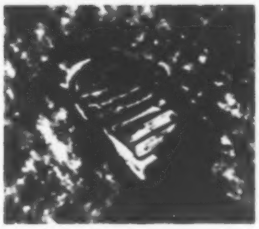
Extensions

Spacecraft design could be conducted as a spin-off of the "egg drop" contest. Each spacecraft is constructed to hold and protect one raw egg. The egg must remain unbroken after landing from a high drop (perhaps a second-story balcony).

Some students may enjoy learning more details of Apollo site selections.
A detailed discussion of how the sites were chosen is given in *To A Rocky Moon* by Don E. Wilhelms, Univ. of Arizona Press, 1993.

Use these lunar landing sites in the "Lunar Roving Vehicle" activity on Page 87, stipulating that the vehicle must be able to work on the terrains.

Use these lunar sites in the "Lunar Land Use" activity on Page 101.



Lunar Landing Sites

Purpose

To design a spacecraft for travel to and from the Moon and chose an interesting lunar landing site.

Materials

Moon maps

Apollo landing sites map

"Moon ABCs Fact Sheet"

Moon slides

background literature, such as the "Teacher's Guide"

"Team Duty Sheet"

art and construction supplies

Scenario

NASA has given you the assignment to develop a spacecraft that can fly people safely to the Moon, land, and return to Earth. You must also select a safe yet interesting lunar landing site for the spacecraft.

Size, weight, propulsion, number of crew, life support systems, and methods of takeoff and landing should be considered for the spacecraft. Geology, terrain, safety, and length of stay should be considered for the lunar landing site.

Procedure

1. Read the "Team Duty Sheet" given to your team.

2. Design a spacecraft with all necessary sytems that can go to the Moon, land, and return to Earth. Build a model or draw a detailed diagram of the design.

3. Study maps of the lunar sufrace and use your knowledge of the Moon to determine a safe yet interesting lunar landing site.

4. Make a presentation to the class:
   (a) about your spacecraft and its special features using diagrams and/or a model,
   (b) describing, locating, and justifing the landing site.

Names: ____

Date: ________________

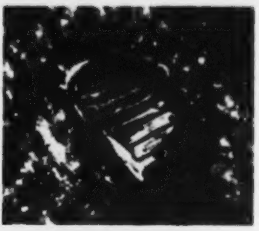
Lunar Landing Sites

TEAM DUTY SHEET

Your team must design a spacecraft and determine a safe yet interesting place to land on the Moon.

Everyone on your team should be assigned one or more of the following duties:

Chief Engineer :	oversees the entire project, helps to design spacecraft, makes critical decisions for the team.
Scientist :	designs spacecraft, oversees the construction of the model or diagrams of the spacecraft.
Lunar Geologist :	studies maps of the Moon and oversees the selection of a safe yet interesting place to land the spacecraft.
Public Relations Manager :	helps scientist and geologist, oversees the presentation of the spacecraft and landing site before the class.



Lunar Roving Vehicle

Purpose

To construct a model of a lunar roving vehicle.

Background

The **Apollo lunar roving vehicle** was a battery-powered space buggy. The **astronauts** on Apollo 15, 16, and 17 used it to explore their landing sites and to travel greater distances than astronauts on earlier missions. The lunar rover neatly folded up inside the lunar lander during trips to the Moon. Once on the Moon's surface, it unfolded with the help of springs. The lunar rover carried two astronauts and was manually driven. It was designed to climb steep slopes, to go over **rocks**, and to move easily over the Moon's **regolith**. It was able to carry more than twice its own weight in passengers, scientific instruments, rocks, and regolith samples. The wheels on the rover were made of wire mesh (piano wire) with titanium cleats for treads. Engineers did not use solid or air-filled rubber tires because they would have been much heavier than were the wire mesh wheels. The Apollo **spacecraft** had a fixed amount of mass (payload) it could deliver to the surface, including the rover, rover batteries, scientific instruments, sample collection devices, etc. Hence, the wire-mesh wheels were important to the overall payload mass. This rover was not designed for prolonged use, and it is uncertain if future lunar explorers would use similar designs and materials for their vehicles, use new, more durable components, or turn to **robotic** rovers.

If students are interested in constructing models that actually move, then refer to Page 38 for more information on rocket and model building.

Preparation

Review and prepare materials listed on the student sheet. While commercial building sets are very popular, models can be built with more simple and recyclable materials such as cardboard boxes, tubes, cans, straws, construction paper, string, tape, pins, styrofoam trays, thread spools, balloons, rubber bands, and mouse traps (for propulsion).

In Class / Wrap Up

After construction, students should name their vehicles and write a description of the capabilities and special features.

Lunar Roving Vehicle

Extensions

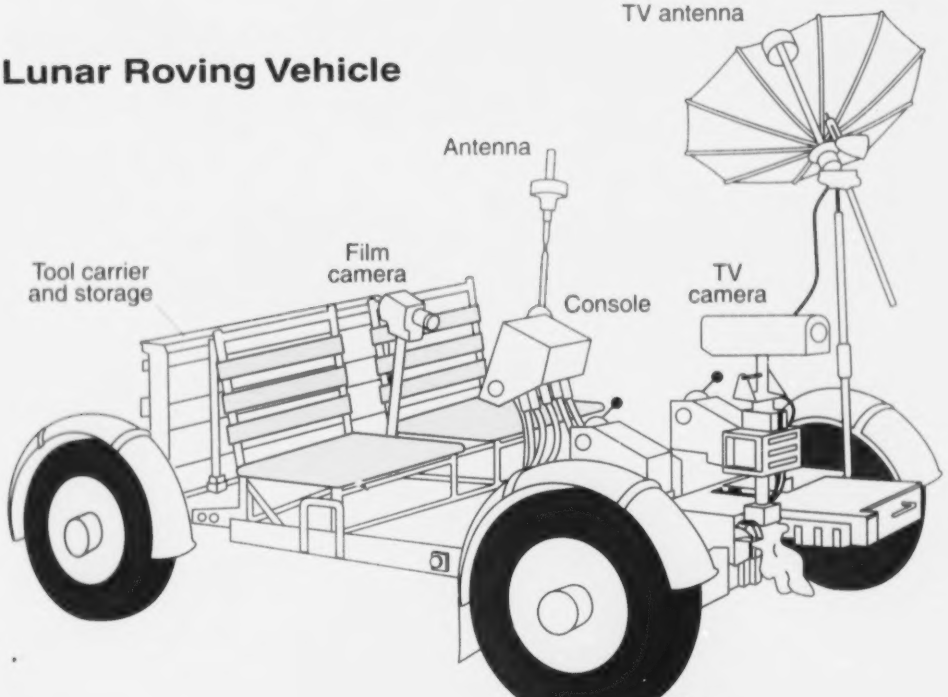
Hold competitions between student vehicles with these criteria for judging:

1. Can the vehicle actually move -- by gravity; by some kind of propulsion system?
2. Can the vehicle go over different surfaces -- smooth, flat, bumpy, or inclined?
3. Is the vehicle sturdy?
4. Can the vehicle carry a heavy load? Have the students decide the weight of the load.
5. Could the vehicle withstand meteoritic bombardment?
6. Would the vehicle work on the Moon?

Discuss the pros and cons of manually driven vehicles versus remote-controlled robotic rovers on the Moon.

Diagram of the vehicle used by Apollo astronauts.

Lunar Roving Vehicle



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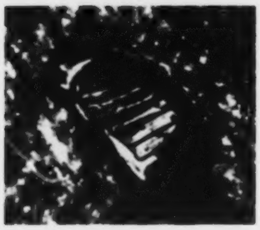


Lunar Roving Vehicle

Purpose

To construct a model of a lunar roving vehicle.

Key Words

antenna

console

tool carrier and storage

robot

Materials

diagram of Apollo lunar roving vehicle

"Moon ABCs Fact Sheet"

construction materials such as cardboard boxes, tubes, cans, straws, construction paper, string, tape, pins, styrofoam trays, thread spools, balloons, rubber bands, mouse traps, etc.

tape measures

stop watches

Procedure

1. Describe the similarities and differences between the Apollo lunar roving vehicle and a typical family vehicle.

2. What was special about the rover's wheels? Why weren't they made of rubber and filled with air?

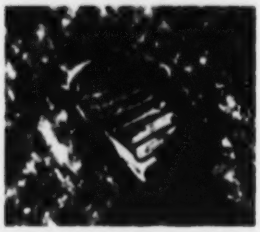
3. Review the "**Moon ABCs Fact Sheet.**" Design a new lunar roving vehicle. Important design issues include size, weight, power supply, number of passengers, controls, scientific instruments, tools, and storage compartments. Use the space provided on the next page to draw a picture of your design. Label the parts.

4. Construct a model of the lunar rover based on your design.

5. Give a name to the vehicle.

6. Write a descriptive essay about the special features and capabilitites of the vehicle and how you solved the design issues raised in Question 3.

Sketch of my model



Moon Anomalies

Purpose

To investigate and try to explain various lunar anomalies.

Background [also see "Teacher's Guide" Pages 4, 10]

In this activity teams of students present hypotheses that attempt to resolve four anomalies of the Moon. They will be expected to prepare written and oral presentations for the entire class. Using a forum format, students will debate the merits of each hypothesis, with no right or wrong answers.

The four anomalies are:
"Quakes or No Quakes, that is the Question"
"Where Have All the Volcanoes Gone?"
"Maria, Maria, Where For Art Thou?"
"Magnetic Field Forever?"

Some of these anomalies are more complicated than others. The class need not discuss all the anomalies; the most straightforward are Quakes and Missing Volcanoes.

Preparation

Review and prepare materials listed on the student sheets.
Schedule library time, if needed.

Some possible solutions to the anomalies

Quakes or No Quakes, that is the Question

The number and strength (magnitude) of **moonquakes** is much less than the number and magnitude of **earthquakes**. The probable cause of this difference is the Moon's smaller size and cooler interior. Earth is hot and active, manifested most dramatically in **plate tectonics**. Tectonic plate motions in Earth are driven by convection in the **mantle**—the solid mantle actually moves at rates of a few centimeters a year. The Moon's mantle, too cool to move easily, has no convection and no active tectonic plate motions. Fewer movements inside the Moon mean fewer quakes. The few moonquakes that do occur are driven primarily by gravitational tugs by Earth and Sun (tides in the solid Moon).

Moon Anomalies

Where Have All the Volcanoes Gone?

The Moon has lots of **lava** flows, but no (or at least few) **volcanoes**. The clue to solving this dilemma lies in understanding why volcanoes form on Earth, Mars, and Venus. In fact, those bodies also have large expanses of lava flows that are not associated with volcanoes. For example, vast deposits of lavas occur in Oregon, Washington, and Idaho. These are called the Columbia River Basalts. They **erupted** from long cracks called **fissures** and flowed across the surface. The path the magma took was far different from that in other places. The magma never concentrated to narrow conduits that were fed periodically over a long time to form a high mountain over the site.

The transport of magma for the Columbia River basalts was controlled by the stress environment of the region. Long fissures developed which provided the magma with pathways to the surface. On the Moon, plenty of fractures occur around the rings of the multi-ringed basins. These fractures undoubtedly extend far into the Moon, and may have provided easy access to the surface for magma, and at the same time did not allow the magma paths to concentrate in one small area. Result: no large volcanoes formed. The idea that some did form but were destroyed by impacts is always a possibility on the Moon, but lots of volcano-sized mountains on basin rings survived, so one would expect volcanoes to do so, too.

Maria, Maria, Where For Art Thou?

Almost all of the lunar maria decorate the Earth-facing side of the Moon. Only a few add contrast to the **farside**. See the first two photographs in the "Teacher's Guide" on Page 1. The most likely cause of this asymmetry is the variation in thickness of the Moon's **crust**. The crust is lower in density than the mare-basalt magmas that must pass through it to erupt onto the surface. This, in turn, requires that the magmas have a sufficient driving pressure to migrate through the crust. Scientists think that magmas on the Moon tend to stall and collect at the base of the crust. They stay there until the pressure is enough to begin to form fissures for the magmas to travel through. On the nearside, the crust is about 70 kilometers thick. Many of the mare-basalt magmas were able to reach the surface once the pressure was large enough to form cracks. However, on the farside, the crust is twice as thick, so very few magmas could reach the surface. Most stalled on their way through it.

Magnetic Field Forever?

The lunar **magnetic field** is one of the least understood properties about the Moon. It is about 10,000 times weaker than Earth's magnetic field. The Moon had a weak field in the past, but none is being generated at the present time.

continued on next page

Moon Anomalies

The most likely reason for the decline in field strength is that the Moon's tiny metallic **core** (no larger than 400 kilometers in radius) did generate a field the way Earth's core does, but the field-generating engine kept losing power. Earth's field is generated by convective motions inside the liquid portion of the core: hotter iron rises, cooler iron sinks, and the differential motions create a magnetic field. On the Moon, the whole body cooled much faster than Earth (because the Moon is smaller), so the core also cooled, and probably solidified. Motions fast enough to generate a magnetic field do not occur today inside the Moon's core.

In Class

Divide the class into cooperative teams of 4-5 students. Encourage each team to generate a team name and logo. Give each team a "Task Sheet" describing their duties. Each team then develops a hypothesis that reconciles the dilemma given them. They must work together to produce a written report describing their anomaly, hypothesis, and supporting evidence. You may want to copy and distribute all the final reports so each team has a complete set.

When the teams make their oral presentations to the class they must use visual aid materials, such as maps, posters, charts, slides, laserdiscs, etc. After each presentation, other teams may challenge the presenters with questions or arguments.

Wrap-up

After all teams have presented, lead a discussion to summarize what has been learned.

Extension

You may wish to discuss another mysterious aspect of the Moon's magnetic field: the presence of several small areas (30-60 kilometers across) that have exceptionally large surface magnetism, about 10 times the normal Moon magnetic field. These are associated with bright swirly deposits. Possible origins include impact of a comet that is highly magnetized or magnetization of a comet during impact. In either case, the magnetism is transferred to the ejecta deposits at the site of impact. Another suggestion is that the field results from giant, basin-forming impacts. It turns out that most, but not all, magnetic swirl deposits are on the exact opposite side of the Moon from a large basin (i.e., antipodal to the site of impact). The idea is that seismic waves generated by the large impact interact vigorously when they meet half way around the Moon. Somehow these interactions reinforce existing magnetic fields to create the anomaly. The whitish swirls, by the way, may form because the solar wind (mostly hydrogen nuclei) is deflected by the strong magnetic field. Thus, no hydrogen gets implanted into the regolith, and subsequent micrometeorite bombardment does not cause formation of dark agglutinates. Instead of being dark glass, the agglutinates are colorless or nearly so.

Names: ____

Date: ____________

Moon Anomalies

Task Sheet

Everyone on your team should be assigned one or more of the following tasks:

Chief Stratigist :	oversees the entire project, works closely with all members, makes critical decisions.
Material Person :	collects, cares for, and returns all materials needed for the activity.
Media Consultant :	oversees development of all the visual aid materials that your team will use during the presentation, such as maps, posters, models, etc. Also coordinates the use of slides, photographs, laserdisc, etc.
Administrator :	keeps notes, assists media consultant, and prepares final written report.

The oral presentation may be made by any one or all team members.

Quakes or No Quakes, that is the Question

Purpose

To investigate and try to explain why the Moon has fewer moonquakes than Earth has earthquakes.

Key Words

earthquake

moonquake

Materials

maps of the Moon

background information on the Moon

"Moon ABCs Fact Sheet"

"Task Sheet"

art supplies

Background

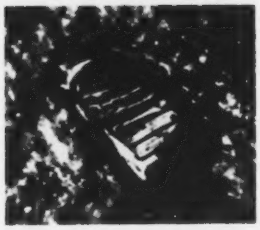
The Moon is safer than San Francisco—at least from earthquake damage. Each year Earth has more than 10,000 earthquakes of magnitude 4 or greater. In contrast, the Moon has less than 500, and most of these are smaller than magnitude 2.5. The largest moonquake recorded during the eight years that the Apollo seismic instrument operated on the Moon was slightly less than magnitude 5. On Earth, the largest quakes reach magnitude 8, or even 9. Finally, the total amount of energy released by moonquakes is the same as released by three 100-watt light bulbs. Earthquakes release the equivalent of 300,000,000 100-watt light bulbs.

Dilemma

Why does the Moon have fewer quakes than Earth? Is it because people live on Earth? Because the Moon is smaller? Because Earth has moving tectonic plates? Because the Moon has craters?

Task

Develop an hypothesis that explains why the Moon has fewer quakes than Earth.



Purpose

To investigate and try to explain the absence of volcanoes on the Moon.

Key Words

volcano

lava flows

maria

Materials

maps of the Moon

background information on the Moon

"Moon ABCs Fact Sheet"

"Task Sheet"

art supplies

Background

The dark areas of the Moon's surface, called the lunar maria, are composed of solidified lava flows. Scientists know this from photographs that show the margins of individual lava flows and from examination of rocks returned from the maria. The lava plains cover 16% of the lunar surface and are up to about 2 kilometers thick. This is a substantial amount of lava. Scientists estimate that a total of 10 million cubic kilometers of lava erupted during a period of about a billion years to fill the mare basins. This is a lot of lava! -- enough to fill 10 billion football stadiums! Most of the maria occur inside the huge circular impact craters called multi-ringed basins. The formation of these immense craters did not cause the formation of the lava that made the maria, but the basins did provide low areas into which the liquid lava flowed.

Dilemma

Ten million cubic kilometers of lava flowed across the Moon's surface, yet there are no obvious source volcanoes. There are no mountains that rise dramatically as they do in Hawai'i or the Cascades of the Pacific Northwest. If there are no volcanoes on the Moon, then what is the source of the lava? Were the volcanoes destroyed? Did the lava erupt in some other way? What other ways could lava erupt?

Task

Develop an hypothesis that resolves the missing volcanoes dilemma, without rejecting the idea that the maria are composed of solidified lava flows.

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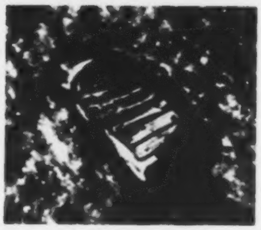

Purpose

To investigate and try to explain why the farside has fewer maria than the nearside of the Moon.

Key Words

maria

crust

lava flows

Materials

- maps of the Moon
- background information on the Moon
- "Moon ABCs Fact Sheet"
- "Task Sheet"
- art supplies

Background

About 16% of the Earth-facing side of the Moon is covered with dark maria. But less than 1% of the farside is covered with maria. Scientists think that the magmas were formed inside the Moon by melting of the Moon's mantle, and that these magmas then moved to the surface. They probably moved in long cracks. Good evidence suggests that the crust on the farside is about two times thicker than on the nearside.

Dilemma

Assuming magma was generated throughout the Moon's mantle, why are almost all the maria on the nearside of the Moon? Did they get covered up by other rocks on the farside? Did Earth's gravity help them get out onto the nearside? Was it too hard to travel through the thick, farside crust?

Task

Develop an hypothesis that resolves the maria-are-more-abundant-on-the-nearside dilemma.

Magnetic Field Forever?

Purpose

To investigate and try to explain why the Moon has a weaker magnetic field than does Earth.

Key Words

magnetic field

core

Materials

background information on the Moon

"Moon ABCs Fact Sheet"

"Task Sheet"

art supplies

Background

The Moon has a much weaker magnetic field than does Earth. However, the field was stronger in the past, as shown by study of the magnetic properties of lunar rocks. Earth's magnetic field is formed by motions inside its iron core. The Moon also has a core, but it is much smaller than Earth's core. The Moon's core is no larger than 400 kilometers in radius, and may be as small as 100 kilometers. In contrast, Earth's core is 2900 kilometers in radius.

Dilemma

The Moon had a stronger magnetic field in the past (billions of years ago), but it is weak now, much weaker than Earth's magnetic field. Why is it so much weaker than Earth's? Why was it stronger in the past?

Task

Develop an hypothesis that explains why the Moon has a weaker magnetic field than does Earth, and why the Moon's field was stronger in the past.

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Unit 3

The Future

Lunar Land Use
Life Support Systems
Lunar Biosphere

The activities in this unit spark interest in responsible land use and sustainable human settlements on the Moon. Each activity uses and reinforces all the knowledge the students have been gaining about the Moon and Earth from Units 1 and 2. These activities require teamwork, research, and development of model systems.

A Resource Section for Unit 3 is on Page 100.

Unit 3

Resource Section

This list presents possible independent and commercial sources of items to complement the activities in Unit 3. The sources are offered without recommendation or endorsement by NASA. Inquiries should be made directly to the appropriate source to determine availability, cost, and ordering information before sending money. Contact your NASA Teacher Resource Center (see pages 147-148) for more lists of resources available directly from the National Aeronautics and Space Administration.

Bottle Biology, by the Bottle Biology Project, 1993, Kendall/Hunt Pub. Co., 127 p. An idea book for exploring the world through plastic bottles and other recyclable materials.
Dept. of Plant Pathology, College of Agricultural and Life Sciences, University of Wisconsin-Madison
1630 Linden Dr.
Madison, WI 53706
608-263-5645

110

Lunar Land Use

Purpose

To design a development on the Moon that is suitable, feasible, and beneficial.

Background [also see "Teacher's Guide" Pages 14, 15]

In this activity teams of students will present proposals for developments on the Moon in a competition for approval from a student-staffed Lunar Council. This activity commonly runs 8 class days.

Preparation

Review and prepare materials listed on the student sheet.

In Class

Present the scenario and divide the class into cooperative teams of 4-5 students. Each team will represent a development corporation that will make a proposal before the Lunar Council.

You will also need 3 other students to comprise this Lunar Council.

Each student will have assigned duties, as described on the reproducible "Information Sheets."

Scenario: Travel to and from the Moon has become economical. As a result, the Moon's development has become inevitable and several corporations have already approached the United Nations about the prospects of developing lunar projects. In response, the U.N. has set up a Lunar Council to consider the feasibility and suitability of each proposal.

You may want to brainstorm ideas with the class for projects on the Moon; they may include mining communities, scientific bases, telescopic outposts, government headquarters, recreational bases, tourist sites, etc. You could assign a different idea to each team.

Distribute an "Information Sheet" to each development team. Give them 3-5 days to decide what their developments will be and to design their maps, models, diagrams, etc. Not only must they present their plan before the Lunar Council, but they must convince the council of the plan's worthiness. Lobbying efforts and advertising are all part of the game as long as they are fair.

Lunar Land Use

Distribute "Information Sheets" to the Lunar Council. Their task is to organize and run a hearing regarding development on the Moon. The ultimate approval for development is in their hands.

When most of the teams have finished, let the Lunar Council set the hearing date and let the proceedings begin.

Wrap-up

Once a decision is rendered, distribute the "Wrap-up Questions" or discuss them as a class.

Extensions

1. Have the students bid for project sites or use the landing sites chosen in the "Lunar Landing Sites" activity on Page 83.
2. Hold a classroom debate on "Who owns the Moon?"
3. Have the students compare Antarctica to the Moon.

Lunar Land Use

Purpose

To design a development on the Moon that is suitable, feasible, and beneficial.

Key Words

development

feasible

beneficial

Materials

maps of the Moon

"Moon ABCs Fact Sheet"

backgound information on the Moon

"Information Sheets"

art and construction supplies

Scenario

Travel to and from the Moon has become economical; as a result, the Moon's development has become inevitable. Several corporations have already approached the United Nations with lunar proposals.

In response, the U.N. has set up a Lunar Council to look at the suitability and feasibility of each proposal.

If your team is one of the development corporations, then your job is to decide what you want to build on the Moon and where to put it, to make the maps, diagrams, and/or 3-dimensional models of your project, and to convince the Lunar Council that your project is worthy of approval.

If you are a Lunar Council member, then the development of the Moon rests on your decisions.

Procedure

1. Read the "Information Sheet" given to your group, either a development team or the Lunar Council, and divide the duties.
2. Each development team must execute a development plan and design all necessary maps, diagrams, and/or 3-dimensional models.
3. Each development team must follow the guidelines set forth by the Lunar Council.
4. Each development team must present a plan for approval.
5. The Lunar Council reviews all the plans and decides which, if any, will be accepted.

Names: ____

Date: ______________

Lunar Land Use

Team Member Information Sheet

Tasks

Your team must decide what you want to build and where you want to build it. Everyone on your team should be assigned one or more of the following tasks:

Chief Engineer :	oversees the entire project, makes critical decisions, assists in the design of the project.
Lunar Geologist :	studies the Lunar Sample Disk and researches the minerals that may exist on the Moon for mining and/or for use as building materials. Chooses a suitable site for the project.
Media Consultant :	oversees development of all the visual aid materials your team uses to present your proposal, such as maps, posters, and models. Also coordinates the use of slides, photographs, laser disc, etc. used to enhance your presentation.
Administrator :	keeps notes, assists media consultant, works closely with the reporter to develop the speech to be given to the Lunar Council and types this final written proposal.
Reporter :	works closely with all members to write the speech that will be given before the Lunar Council. The actual presentation may be made by any one or all team members.

Remember, you will have to "sell" your ideas before the Lunar Council. You need a well-planned project. Focus on how your project will be used, how it will benefit people, how it is environmentally friendly, etc.

Anything goes as long as it is actually possible. For example, if you are asked where the money is coming from to back your project you could say you have investors who will recover their money plus interest when the project makes money. You cannot have stories like "a limousine drove by and out popped a suitcase full of money." Have fun!

Names: ______________________________

Date: ____________

Lunar Land Use

Lunar Council Information Sheet

Tasks

You are representatives of the United Nations and have been chosen to decide how the Moon will be developed. Your job is to organize and run a hearing where various teams will make proposals to you concerning the development of the Moon. Your ultimate task will be to choose one or more of the proposals brought before you. If you wish, you can choose none of the proposals or allow certain ones with restrictions or improvements.

Everyone on the Council should hold one of the following positions:

Chairperson :	runs the hearing by calling on the teams for their presentations, calls on Council members and the public to ask questions, makes critical decisions for the Council, announces the final decisions.
Timekeeper :	decides how long the presentations and the question/answer period will last, keeps track of time during the hearing, and stops teams that go overtime.
Administrator :	develops rating sheet with other members, keeps notes, writes, and sends out any bulletins to the development teams.

116

Names: ____

Date: ________________

Lunar Land Use

Lunar Council Information Sheet

Bulletins and Ratings

Your Council should issue bulletins periodically to give guidelines and announcements to all the development teams. An example is given below:

Lunar Council Bulletin 1-1

To: All development teams
From: Lunar Council
Regarding: Hearing timeline and financial background

We have decided to allow each team 5 minutes to make their presentations following which the Council will have 10 minutes for questions and answers. Finally, the public will have another 10 minutes for questions and answers. Any variation to this policy will require permission from the Council before the hearing.

Council members also will be asking you for your sources of money. We want to be sure that if your proposal is chosen, you will be able to build it.

You also will need to develop a rating sheet to judge each team fairly. An example is given below:

Group #	Feasibility 1-10	Pollution 1-10	Income 1-10	Planning 1-10	TOTAL
1					
2					

After all the teams have made their presentations, the Council retires and renders a decision on which team, if any, will be allowed to develop.

Names: ____

Date: ______________

Lunar Land Use

Wrap-up Questions

1. Did your team work together well? Why or why not?

2. Do you think it is important to have hearings like this one before the Moon is developed? Why or why not?

3. Do you think the Lunar Council's decision was fair? Why or why not?

4. Should we allow developments on the Moon? Why or why not?

5. Do you think the Moon should belong to everyone or to whomever can get there and use it first? Why?

6. How is the Moon and its development similar to the development of Antarctica?

7. What kind of environmental problems do you think we need to be aware of on the Moon?

Life Support Systems

Purpose

To design and build models of life support systems for a settlement on the Moon.

Background [also see "Teacher's Guide" Pages 14, 15]

A future lunar base will have to be a self-contained habitat with all the life support systems necessary for the survival of people, animals, and plants. In this series of activities, the students will be designing and building models of nine life support systems which are crucial to our successful settlement of the Moon.

The nine life support systems are:

"Air Supply,"
"Communications,"
"Electricity,"
"Food production and delivery,"
"Recreation,"
"Temperature control,"
"Transportation,"
"Waste management," and
"Water supply."

This activity is based on the Marsville activity on life support systems developed by the Challenger Center and is used with permission.

Preparation

Review and prepare materials listed on the student sheets. Separate student activity sheets are included for each of the nine life support systems. Spaces for answers are not provided on all sheets, so students will need extra paper.

In Class

After dividing students into teams, you may want to have each person assume a role on the team, e.g., organizer, recorder, researcher, builder, artist, writer, etc. Distribute a student activity sheet to each team.

Life Support Systems

Each team must define the requirements of their system, exploring how these requirements are currently being met on Earth. Team members will research the limitations and/or opportunities posed by the Moon's environment. The "Moon ABCs Fact Sheet" and maps of the Moon should be used as resource materials.

Each team will decide how the system will operate and what it will contain. A key part of the problem-solving process is the students' ability to evaluate the system solution in terms of whether it provides the greatest good and least harm to the persons and things affected.

Each model of a life support system must incorporate at least four facts from the "Moon ABCs Fact Sheet."

Models do not have to function physically, but each team member must be able to explain how the models should function.

Wrap-up

Have each team share what they have learned with the entire class.

1. Did the students find that the Moon's environment placed limits on their designs of life support systems?
2. Did the students find opportunities for development on the Moon that could not happen on Earth?
3. Summarize the aspects and conditions of the Moon which make life support such a challenge.

Air Supply

Purpose

To design and build a model air supply system for a human settlement on the Moon.

Key Words

atmosphere

photosynthesis

Materials

"Moon ABCs Fact Sheet"

construction materials such as cardboard boxes and tubes, blocks, hoses, straws, string, pins, rubber bands, tape, etc.

Procedure

1. The atmosphere of Earth is a combination of several gases; review them from the "**Moon ABCs Fact Sheet**." What gas do humans and animals need to breathe in?
2. What primary gas do humans and animals breathe out?
3. What is photosynthesis?
4. During the process of photosynthesis, what gas must green plants take in ?
5. What gas do the green plants produce?
6. A process called electrolysis can separate water into hydrogen gas and oxygen gas. Another process is being developed which can extract oxygen from rocks and soil that contain it. Do you think these processes could be useful on the Moon? How?

Air Supply

7. Review the "Moon ABCs Fact Sheet." Will the Moonbase settlers automatically be able to breathe the atmosphere or will special provisions need to be made?

8. Design an air supply system to be used by the Moonbase inhabitants which will rely on oxygen and carbon dioxide available only from the Moon's resources. You may assume that ample electricity will be available.

9. Construct a model of this system based on your design. It must include the application of at least four facts from the "Moon ABCs Fact Sheet." For example, how will the Moon's gravity affect the design of your system? Maybe your system will be very heavy but still portable by only a few Moonbase workers because the Moon's gravity is only 1/6th of Earth's gravity.

Sketch of my model

Communications

Purpose

To design and construct a model of a communications system to be used by people living and working on the Moon.

Key Words

communications

Materials

"Moon ABCs Fact Sheet"

construction materials such as cardboard boxes and tubes, blocks, hoses, straws, string, pins, rubber bands, tape, etc.

Procedure

1. What different ways do we have of communicating with each other here on Earth? Do some methods work better short distance than long distance? What are the strong points of each of these methods? What limitations does each have?

2. Why do you think communication would be important in each of the following situations:

   - Between Moonbase settlers within their constructed settlement.

   - Between settlers in the settlement and those conducting missions elsewhere on the surface of the Moon.

   - Between Moonbase and Earth (How long does it take for a radio signal to travel the distance between Earth and the Moon?)

3. Review the facts you have learned about the Moon. Do you think any of the communications methods on Earth (from Question 1) would be impractical on the Moon? Why or why not? Which communications methods on Earth do you think would be particularly useful on the Moon? What features of these methods might you have to modify?

4. Design a communications system to be used by the Moonbase inhabitants which will have components to satisfy the different situations listed in Question 2. You may assume that ample electricity will be available.

5. Construct a model of this system based on your design. It must include the application of at least four facts from the "**Moon ABCs Fact Sheet.**" For example, how will the Moon's gravity affect the design of your system? Maybe your system will be very heavy but still portable by only a few Moonbase workers because the Moon's gravity is only 1/6th of Earth's gravity.

Sketch of my model

Electricity

Purpose

To design and build a model electrical power supply system for a human settlement on the Moon.

Key Words

electricity

solar power

nuclear energy

Materials

"Moon ABCs Fact Sheet"

construction materials such as cardboard boxes and tubes, blocks, hoses, straws, string, pins, rubber bands, tape, etc.

Procedure

1. Think of all the things you do during a regular school day, from the minute you wake up until the time you go to sleep. List each activity which requires electricity.

2. What other activities in your town, city, or state use electricity?

3. What is the source of the electric power for your town or city? Is it a steam generating plant that burns natural gas, oil, or coal? Is it a nuclear-fission plant?

4. List other ways to produce electricity.

5. How is electricity transmitted from the generating plant to other places?

6. Review the facts you have learned about the Moon. Do you think the lack of atmosphere, natural gas, oil, and coal on the Moon would affect the production of electricity? How? Would materials have to be shipped from Earth? Should the lunar settlement rely on materials shipped from Earth? Your team's job is to supply the electricity needed by the life support systems at the Moonbase.

7. Review the "**Moon ABCs Fact Sheet.**" Design an electrical power generating plant and transmission system for the Moonbase inhabitants. Important issues to consider include pollution, radioactive waste storage, length of daylight on the Moon, and power storage.

8. Construct a model of this system based on your design. It must include the application of at least four facts from the "Moon ABCs Fact Sheet."

Sketch of my model

Food Production

Purpose

To design and build a model of a food production and delivery system for a human settlement on the Moon.

Key Words

food groups

nutrition

consumption

self-sustaining

Materials

food groups chart

"Moon ABCs Fact Sheet"

construction materials such as cardboard boxes and tubes, blocks, hoses, straws, string, pins, rubber bands, tape, etc.

Procedure

1. Review the basic food groups. What are examples of food in each group. What basic jobs for the body does each group perform? Make a chart on a separate paper with your answers.

2. With your class, make a list of the foods and liquids everyone consumed in the past 24 hours. Organize your list in the following way: Put each food group in a different column; then cross out all the items you consider "junk food" and cross out each item made from an animal which must eat another animal to live.

3. We know that, with the exception of carnivores, animals eat plants. But what do green plants "eat" in addition to carbon dioxide, sunlight, and water? Include in your answer a discussion of the nitrogen cycle.

4. It is likely that space in the Moonbase will be limited. Protein sources like cattle and vegetable sources like corn require substantial space for production. Reviewing your list from Question 2, what are other sources of protein which take less space? What fruits and vegetables could be produced in limited space?

5. Review the "**Moon ABCs Fact Sheet**" to determine what conditions of sunlight exist. Remember that other teams are responsible for providing you with a water supply (which will probably have to be used cautiously or rationed,) with electricity, with a temperature control system in the constructed Moonbase, and with an air supply of carbon dioxide and oxygen for plants and animals you wish to grow. Remember also that all original stocks of plants and animals must be transported from Earth. With these reminders, your task is to design a food production and delivery system in the Moonbase which will:

   a) supply the inhabitants with all of their nutritional needs,

   b) be self-sustaining without additional stock from Earth, and

   c) provide products appealing enough that the inhabitants will enjoy eating their meals.

6. Construct a model of this system based on your design. It must include the application of at least four facts from the "Moon ABCs Fact Sheet." For example, how will the Moon's gravity affect the design of your system? Maybe your system will be very heavy but still portable by only a few Moonbase workers because the Moon's gravity is only 1/6th of Earth's gravity.

Recreation

Purpose

To design and build a model of recreational facilities for a human settlement on the Moon.

Key Words

entertainment

sedentary lifestyle

active lifestyle

Materials

"Moon ABCs Fact Sheet"

construction materials such as cardboard boxes and tubes, blocks, hoses, straws, string, pins, rubber bands, tape, etc.

Procedure

1. What value does entertainment have?

2. What do you do for entertainment? Brainstorm other forms of entertainment which people enjoy doing.

3. Reviewing your list from Question 2, what activities require you to consider the physical environment? What features of the environment does each activity depend upon?

4. What value do you think entertainment would have on the Moon? (Would the Moonbase settlers need entertainment?)

5. Review the "**Moon ABCs Fact Sheet.**" Which of the recreational activities on your list do you think would be possible on the Moon? Include in your answer which activities would be the most practical and popular.

6. Remembering that the Moon has features different from those of Earth, what might be applied to developing new forms of recreation?

7. Design recreational facilities for the Moonbase inhabitants which satisfy any special recreational needs you think they will have and include some new forms of recreation based on the "Moon ABCs Fact Sheet." You may assume that ample electricity will be available.

8. Construct a model or models of the facilities based on your design. It must include the application of at least four facts from the "Moon ABCs Fact Sheet." For example, how will the Moon's gravity affect your designs?

Temperature Control

Purpose

To design and build a model temperature control system for a human settlement on the Moon.

Key Words

Farenheit

Celcius

Materials

"Moon ABCs Fact Sheet"

construction materials such as cardboard boxes and tubes, blocks, hoses, straws, string, pins, rubber bands, tape, etc.

Procedure

1. Review the clothes you and your classmates wear during each season of the year, both indoors and outdoors. You may want to write this information on a chalk board or paper.

2. How many degrees does the temperature have to change for you to switch from shorts to jeans, from bare hands to gloves, or to add a shirt over a swimming suit?

3. What effect do Sun, clouds, wind, and your own activity level have on the temperature choices you just made?

4. What are the coldest and hottest temperatures you ever experienced?

5. What is the number of degrees between these two extremes you felt?

6. Besides your selection of clothing, what other precautions did you take to protect your body?

7. Think back to a severe hot spell or cold snap your town experienced or that you heard about. List the effects of these temperature extremes on soil, plants, animals, buildings, water use, and electrical use.

8. What different environments on Earth (both indoor and outdoor) could be uncomfortable or actually dangerous to us if we did not control the temperature to which our bodies were exposed?

9. What different ways do we have of controlling the temperature on Earth?

10. Review the "**Moon ABCs Fact Sheet.**" How do temperatures on the Moon compare with temperatures on Earth? Will the Moonbase inhabitants be able to exist without special temperature controls on the surface of the Moon? How about in their constructed Moonbase settlement?

11. Design a temperature control system to protect the Moonbase inhabitants and their possessions/equipment both on the surface of the Moon and in their settlement. You may assume that ample electricity will be available.

12. Construct a model of this system based on your design. It must include the application of at least four facts from the "Moon ABCs Fact Sheet." For example, how will the Moon's gravity affect the design of your system? Maybe your system will be very heavy but still portable by only a few Moonbase workers because the Moon's gravity is only 1/6th of Earth's gravity.

Transportation

Purpose

To design and build a model transportation system for a human settlement on the Moon.

Key Words

transportation

Materials

"Moon ABCs Fact Sheet"

construction materials such as cardboard boxes and tubes, blocks, hoses, straws, string, pins, rubber bands, tape, etc.

Procedure

1. What are some different ways we transport people and goods on Earth?
2. What physical features of Earth do these methods require in order to function?
3. Write down the strong points and limitations of each transportation system you listed in Question 1.
4. What do you think would need to be transported on the Moon in each of the following situations:
    a) within the Moonbase settlement,
    b) between the settlement and other points on the Moon.
5. Review the "**Moon ABCs Fact Sheet.**" Do you think any of the transportation methods on Earth (from Question 1) would be impractical on the Moon? Why or why not?
6. Which transportation methods on Earth do you think would be particularly useful on the Moon? What features might you have to modify?
7. Design a transportation system to be used by the Moonbase inhabitants which will have components to satisfy the different situations they could encounter (Question 4). For this activity you may assume that some of the basic construction materials you need will be transported from Earth to the settlement. You may also assume that ample electricity will be available.

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8. Construct a model of this system based on your design. It must include the application of at least four facts from the "Moon ABCs Fact Sheet." For example, how will the Moon's gravity affect the design of your system? Maybe your system will be very heavy but still portable by only a few Moonbase workers because the Moon's gravity is only 1/6th of Earth's gravity.

Sketch of my model

134

Waste Management

Purpose

To design and build a model waste management system for a human settlement on the Moon.

Key Words

recycling

biodegradable materials

nondegradable

self-sustaining

Materials

"Moon ABCs Fact Sheet"

construction materials such as cardboard boxes and tubes, blocks, hoses, straws, string, pins, rubber bands, tape, etc.

Procedure

1. Your school, in many ways, is like a miniature town. It has a system for governance, health care, traffic control, a work schedule for its inhabitants, recreation, AND waste disposal. To get a better idea of how much waste your school generates every week, find out how many students plus teachers, administrators, other staff (and animals, if any) are regularly in the buildings.

2. Next, interview the cafeteria staff and the custodial staff for the answers to these questions:
   (a) What gets thrown away?
   (b) How many pounds get thrown away every week? Calculate how many pounds of trash this is for every person in the school.
   (c) Are there any items which can be recycled before disposal? If yes, what are the recycled items?
   (d) What items are biodegradable?
   (e) What is the garbage/trash packed in for removal?
   (f) Where is it taken?
   (g) According to building codes, how many toilets must there be to accommodate all the people?

3. Waste is a "hot" topic in our society. Why? Discuss what you know about the following phrases: Excessive packaging, landfills, toxic waste, disposable plastic goods, nondegradable material, water pollution, and air pollution.

4. In movies like those starring "Indiana Jones," well preserved, ancient artifacts are often found in the desert. Scientists also find preserved artifacts in polar ice; for example, mastodons or ancient people. Why aren't they decayed?

5. Review the "**Moon ABCs Fact Sheet.**" The Moonbase must be an enclosed, self-sustaining settlement. Just like your school, it must perform the basic functions of a town. Other teams are responsible for designing and constructing several other types of systems (air supply, communications, electricity, food production and delivery, recreation, temperature control, transportation, and water supply). Your team's job is to dispose of the waste which could be generated by these systems. Design a waste disposal system for the Moonbase. Be sure to decide what importance, if any, will be given to biodegradable materials, recycling, and the Moon outside of the constructed settlement.

6. Construct a model of this system based on your design. It must include the application of at least four facts from the "Moon ABCs Fact Sheet." For example, how will the Moon's gravity affect the design of your system? Maybe your system will be very heavy but still portable by only a few Moonbase workers because the Moon's gravity is only 1/6th Earth's gravity.

Water Supply

Purpose

To design and build a model water supply system for a human settlement on the Moon.

Key Words

water conservation

drought

Materials

"Moon ABCs Fact Sheet"

construction materials such as cardboard boxes and tubes, blocks, hoses, straws, string, pins, rubber bands, tape, etc.

Procedure

1 Think of all the things you do during a regular school day, from the minute you wake up until the time you go to sleep. List each activity which involves water.

2. Are there any water activities you could eliminate for a day? a week? longer?

3. What other activities in your town use water? Could any of those activities be eliminated?

4. During a dry summer, have you ever heard a public announcement that "water conservation measures are in effect"? What activities are affected by this announcement?

5. Imagine if summer drought continued for years, then how could water be conserved for people? for animals? for crops? for businesses?

6. Review the "**Moon ABCs Fact Sheet.**" Where is the water on the Moon and in what form or forms does it exist?

7. Design a water supply system to be used by the Moonbase inhabitants which will rely only on water available from the Moon's resources. You may assume that ample electricity will be available.

8. Construct a model of this sytem based on your design. It must include the application of at least four facts from the "Moon ABCs Fact Sheet." For example, how will the Moon's gravity affect the design of your system? Maybe your system will be very heavy but still portable by only a few Moonbase workers because the Moon's gravity is only 1/6th of Earth's gravity.

Sketch of my model

Lunar Biosphere

Purpose

To build a biosphere that is a balanced, self-enclosed living system able to run efficiently over a long period of time.

Background [also see "Teacher's Guide" Pages 14, 15]

Earth is the ultimate **biosphere**, literally a "life ball." It holds and sustains all life known to humanity. As men and women look to traveling and living beyond our blue planet, we see conditions that are too harsh to sustain life as we know it.

Conditions on the Moon are not favorable for sustaining life because of the absence of water, organic topsoil, and **atmosphere**. Also **lunar** days (equal to 14 Earth days) and nights are very long. Water must be brought from Earth or made using oxygen from lunar **regolith** and hydrogen from Earth. Nutrients need to be added to lunar regolith and plants have to be grown in a self-enclosed system. What's more, artificial light must be used during the long, dark periods.

This activity challenges students to create a working model of a lunar biosphere that is a balanced, self-enclosed living system able to run efficiently over a long period of time.

Preparation

Review and prepare materials listed on the student sheet. Here are some suggestions.

Seedlings: About two weeks prior to this activity, sprout the seedlings for use in the biospheres. Successful biospheres have been made using mung, radish, and peanut. Tomato seedlings can also be used, as well as ferns, vines, and simple garden weeds.

Soil materials: Collect bins or bags to hold the variety of soil materials: vermiculite, permiculite, cinder, gravel, sand, silt, clay, and fertilizer.

Animals: Students should collect live critters to live in the biospheres. These can include -- insects (ants, cockroaches, beetles, etc.), mollusks (snails, slugs, etc.), arachnids (spiders, etc.), and crustaceans (sow bugs).

Plastic bottles for biospheres: Use 2-liter soda bottles with the black base. Remove the black base by submerging it in a large pot of hot (but not boiling) water. This softens the glue holding the base onto the bottle without melting the plastic. Take off the label. With an exacto knife or razor, cut off the top spout of the bottle. For safety, it is best not to allow students to do the cutting. You may place the spout with your other plastic recyclables as it will not be used in this activity. Prepare one container per student.

Lunar Biosphere

The students will plug the holes in the black base with wax, tape, or clay. The base must be watertight. They will then fill the base with a predetermined soil mixture. They will add water, seedlings, and animals as decided by the team. Finally, they will invert the plastic container into the base, seal it with clear, plastic tape, and label it. The label should include the student's name, names of team members, date, and time the biosphere was sealed.

In Class

After discussing the background information and purpose of this activity, divide the class into cooperative teams of 4 students each.

Biosphere mobiles

Have each team create a hanging mobile with the theme "Biosphere." Each hanging component represents one part of the living Earth system, e.g., water, plants, animals, people, air, Sun, soil, etc.

After mobiles have been balanced and hung from the ceiling, have the students predict what would happen if one part were removed or just shifted. Ask the students to shift or remove one part. Does the biosphere remain balanced? Ask the students to try to rebalance and hang their mobiles. Have them relate what they see to what might happen if a part of any biosphere is changed or removed.

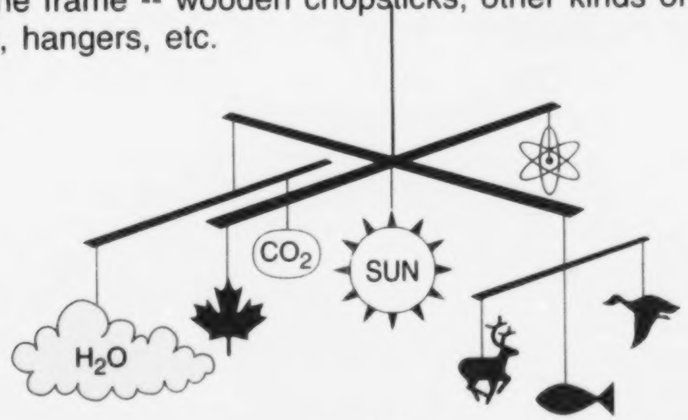
Materials

cardboard or heavy-weight paper

markers or crayons

string

something to use as the frame -- wooden chopsticks, other kinds of sticks, plastic drinking straws, hangers, etc.



Lunar Biosphere

Making Biospheres

After discussing the importance of a balanced biosphere, you may choose to have the students number themselves from 1 to 4 for a role assignment within each team:

1 = **Botanist** - person who studies plants,
2 = **Agronomist** - person who studies soils and crops,
3 = **Science Specialist** - person who relates conditions of soil and water to optimal plant growth,
4 = **Zoologist** - person who studies animals.

Distribute the "Team Member Information Sheets." Students are responsible for reading and sharing the data contained on their own sheets. Have them log their shared information on their worksheet -- as outlined in Question 3 on page 133.

Before the actual construction, each team must decide the following for their lunar biospheres:

1. **best lunar soil mixture**
   for example, vermiculite, permiculite, cinder, sand, gravel, fertilizer, etc.

2. **amounts of each type of soil material**
   for example:
   10 Tablespoons of sand
   10 Tablespoons of silt
   10 teaspoons of vermiculite
   1/2 teaspoon of fertilizer

3. **optimal lighting**
   for example: direct sunlight, shade, artificial lamp, etc.

4. **optimal amount of water to add to the biosphere before sealing it**
   for example: 5 Tablespoons of water

5. **kinds and amounts of seedlings and animals to include inside**
   for example: mung, radish, peanut seedlings -- use just one type or a combination. If these are not available, then other seedlings can easily be used. Other examples include ferns, vines, and garden weeds. Have students explain why they made their choices. Students can also do preliminary research on their organisms.

Note: Each lunar biosphere must include plants and animals.

Lunar Biosphere

After teams have discussed and decided these five points, then each student will make his/her own biosphere.

The biospheres must be completely sealed with clear, plastic tape.
No air or other materials can go in or out.
Once the biosphere is sealed, it cannot be opened again.

Each lunar biosphere should be labeled with the student's name, names of team members, date, and time it was sealed. Put this label on the black base.

After the biospheres are built, they should be set under the lighting conditions chosen by the teams.

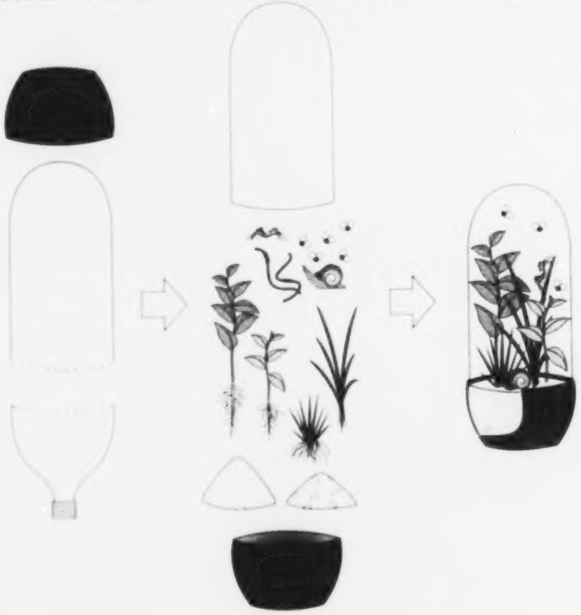
A "Data Sheet" and an "Observation Sheet" are provided for student use.

Wrap-up

Are some lunar biospheres doing better than others?

What are some of the factors leading to the success or failure of the biospheres?

Based on this experience of making a model lunar biosphere, what is your opinion on the potential success of actual self-contained habitats on the Moon?



Lunar Biosphere

Purpose

To build a biosphere that is a balanced, self-enclosed living system able to run efficiently over a long period of time.

Key Words

biosphere
soil
atmosphere
organism
photosynthesis
agronomist
botanist
zoologist

Materials

"Data and Observation Sheets"
"Team Member Information Sheets"
measuring cups & spoons
plastic 2-liter bottle, cut
vermiculite
permiculite
cinder
gravel, sand
silt, clay
fertilizer
seedlings and animals
water
clear, plastic tape
lamp

Procedure for Teams

1. Discuss and list the questions you may want to ask before you start to build a lunar **biosphere.**

2. *How and where could you find possible solutions to these questions?*

3. List all important information you obtained from the **botanist, agronomist, science specialist, and zoologist** that will assist you in planning the most efficient and effective lunar biosphere possible.

Procedure for Each Person

4. Fill out the "**Biosphere Data Sheet**" with your team's choices of best **soil mixture, types and numbers of seedlings and other organisms, optimal lighting conditions, and the optimal amount of water** to add to the biosphere before sealing it. Remember that you are striving to create a living system that will remain balanced over a long period of time.

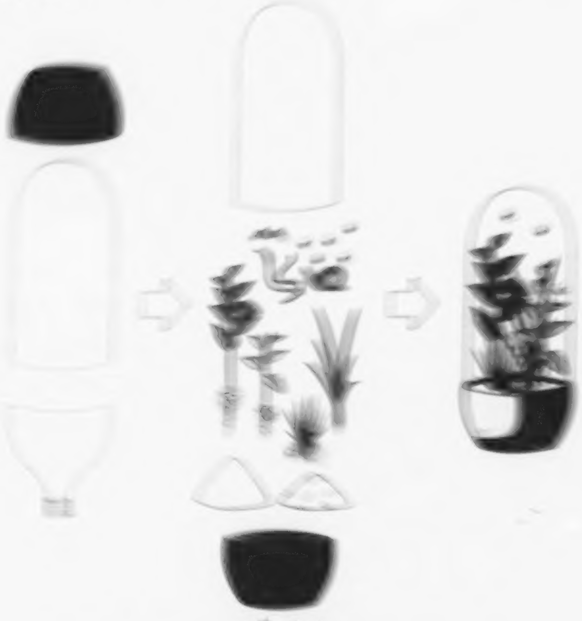
5. Obtain a pre-cut **plastic bottle** from your teacher and build your personal biosphere following the team's recommendations.

6. Seal your biosphere with clear, **plastic tape**. We are simulating a lunar biosphere, therefore no air or other materials can go in or out. After your biosphere is sealed, it cannot be reopened.

7. Label the biosphere with your name, names of your team members, date, and time it was sealed. Put the label on the black base.

8. *Set your biosphere under the* ***lighting*** *conditions chosen by the team.*

9. *Fill in the "****Biosphere Observation Sheet****" as directed by your teacher.*



Team Members:

Name: ______________________________

Date: ____________________

Lunar Biosphere - Data Sheet on Materials Used

Soil Material	Amount Used
Seedlings / Animal organisms	*Amount Used*

Lighting Conditions:

Amount of water added to Biosphere before it was sealed:

Date and Time it was sealed:

Team Members:

Name: ______________________

Date: ______________

Lunar Biosphere - Observation Sheet

Date	Lighting Conditions	Height of Seedlings (cm)			Observations	Color Sketches
		Mung	Radish	Peanut		

Name: ______________________________

Date: ________________

Lunar Biosphere

Team Member Information Sheet

for Botanist

Mung bean, *Phaseolus aureus*
origin: India, central Asia

The mung bean, a bushy annual which grows 76 - 90 meters tall, has many branches with hairy bean-like leaves. Flowers are yellowish-green with purple streaks and produce long, thin, hairy pods containing 9 - 15 small yellow seeds. Seeds are used to produce bean sprouts.

Radish, *Raphanus sativus*
origin: temperate Asia

The radish produces white, red, or black roots and stems under a rosette of lobed leaves. It is an annual or biennial plant, which grows several inches high. Radishes should be planted 1 cm deep, and will sprout in 3 - 7 days. When planted together with other root crops, radishes can be used to decoy pests, and the spaces left in the soil when they are pulled out provide growing room for the other root crops, which grow more slowly.

Peanut, *Arachis hypogaea*
origin: South America

The peanut, an annual vegetable which belongs to the pea family, grows from 15 - 76 cm tall. Flowers are small yellow clusters that grow on stems called pegs. Pegs grow downward and push into the soil. Nuts develop from these pegs 2.54 - 7.6 cm underground.

Name: ______________________

Date: ______________

Lunar Biosphere

Team Member Information Sheet

for Agronomist

Soil has four functions:

1) supply water to plants,
2) supply nutrients (lunar regolith, however, needs to have nutrients added to it),
3) supply gases (oxygen and carbon dioxide), and
4) support plants.

The ideal soil holds moisture and nutrients while letting excess water drain to make room for air.

Types of soil:

clay - small particles, less than 1/256 mm, which pack closely. Poor drainage.
sand - irregular particles between 1/16 mm and 2 mm. Holds very little water.
silt - between clay and sand-size particles. Not very fertile, packs hard.
loam - a mixture of clay, silt, and sand. The best kind of soil.

Name: ______________________________

Date: ________________

Lunar Biosphere

Team Member Information Sheet

for Science Specialist

Growing Conditions

Mung bean - grows best in full sun, in a rich, well-drained soil. It shouldn't be allowed to dry out completely.

Radish - is a cool season crop, and can take temperatures below freezing. It can tolerate partial shade. Soil should be well-drained. If water supply gets low, then radishes become woody.

Peanut - needs lots of Sun and warmth. It is relatively tolerant of dry soil. These seeds are very sensitive to fertilizer.

Soil - can be improved by the addition of fertilizers, which provide nutrients to the plant. This makes the plant healthier, and better able to resist disease and pest attacks.
Vermiculite and perlite are "puffed up" minerals that are used to lighten heavy clay soils with air spaces, or to help sandy soils hold more water. They do not directly provide nutrition to the plants.

Name: ______________________

Date: ______________

Lunar Biosphere

Team Member Information Sheet

for Zoologist

Mung bean - has no serious pest or disease problems.

Radish - has no serious disease problems. Maggots and aphids may be a pest problem, but radishes are usually harvested quickly enough so these do not have much effect.

Peanut - may be attacked by nematodes, aphids, and in some areas, by rodents.

Glossary

Words that appear in *italic* type within a definition also are defined in the Glossary.

A'a: Blocky, angular, and rough type of *lava* flow.

Agglutinates: Common particle type in *lunar sediment*; agglutinates consist of small *rock*, *mineral*, and glass fragments bonded together with glass.

Agronomist: Scientist who studies soil management and the production of field crops.

Anomaly: A deviation from the common rule, type, or form; something abnormal or inconsistent.

Anorthosite: An *igneous rock* made up almost entirely of *plagioclase feldspar*.

Antenna: A conductor by which electromagnetic waves are transmitted or received.

Apollo: U.S. Space Program which included 6 piloted *lunar* landings between 1969 and 1972. Apollo *astronauts* collected and returned 382 kilograms of *rock* and *sediment* samples from the Moon.

Astronaut: Person engaged in or trained for spaceflight.

Atmosphere: Mixture of gases that surround a planet.

Basalt: Fine-grained, dark-colored *igneous* rock compsed primarily of *plagioclase feldspar* and *pyroxene*; other minerals such as *olivine* and *ilmenite* are usually present.

Beneficial: Advantageous, helpful.

Biodegradable (see *Nondegradable*)**:** Capable of decaying and being absorbed by the environment.

Biosphere: The part of Earth's *crust*, water, and *atmosphere* where living organisms can survive.

Botanist: Scientist who studies plant life.

Breccia: Rock consisting of angular, coarse fragments embedded in a fine-grained matrix.

Celsius: A temperature scale that assigns the value 0° C to the freezing point of water and the value of 100° C to the boiling point of water at standard pressure.

Channel: A furrow or narrow passageway in the ground.

Communicatons: A means of transmitting and receiving information.

Console: A desklike structure that is the control unit of an electrical or electronic system.

Consumption: The act of eating or drinking; using energy and materials.

Core: The central region of a planet or moon frequently made of different materials than the surrounding regions (*mantle* and *crust*). Earth and the Moon are thought to have cores of iron and nickel.

Crater (see *Impact*)**:** A hole or depression. Most are roughly circular or oval in outline. On Earth most natural craters are of volcanic origin. On the Moon most are of impact origin.

Crater chain: Several craters along a general line.

Crust: The outermost layer of a planet or moon, above the *mantle*.

Dark mantle deposits: Deposits of dark glass on the Moon, possibly products of volcanic fire fountaining.

Density: Mass per volume; how much material in a given space.

Descartes: *Lunar highlands* site of *Apollo* 16 landing on April 21, 1972.

Development: The act of bringing into being or advancing to a more effective state.

Differentiation: Chemical zonation caused by differences in the densities of minerals; heavy materials sink, less dense materials float.

Drought: Extended period of dry weather, especially one causing damage to crops.

Earthquake: Sudden motion or trembling of Earth caused by the abrupt release of slowly accumulated elastic energy in *rocks*.

Ejecta: Material thrown out from and deposited around an *impact crater*.

Electricity: Energy caused by the motion of electrons, protons, and other charged particles.

Entertainment: Amusement, or diversion; something to hold attention for pleasure.

Erosion: Removal of weathered *rocks* by moving water, wind, ice, or gravity.

Eruption (see *Source*)**:** A break out or brust of volcanic matter.

Glossary

Farenheit: A temperature scale with the freezing point of water assigned the value 32° F and the boiling point of water 212°F.

Farside: The side of the Moon that never faces Earth.

Feasible: Capable of being done or accomplished; probable, likely.

Fissure: Crack extending far into a planet or moon through which *magma* travels to and *erupts* onto the surface.

Food groups: Categories into which all foods are divided; meats and protein, fruits, vegetables, dairy, carbohydrates, and sugars.

Fra Mauro: Landing site of *Apollo* 14 on the Moon on February 5, 1971.

Geologist: Scientist who studies Earth, its materials, the physical and chemical changes that occur on the surface and in the interior, and the history of the planet and its life forms. Planetary geologists extend their studies to the Moon, planets, and other solid bodies in the Solar System.

Giant impact theory: An explanation for the origin of the Moon from Earth debris which collected in space after a *projectile* the size of planet Mars smashed into a growing Earth.

Hadley-Appenine: Landing site of *Apollo* 15 on the Moon on July 31, 1971.

Highland "soil": *Sediment* on the surface of the *lunar highlands*; composed of broken *rock* and *mineral* fragments, and glass produced by *impact*.

Highlands: Oldest exposed areas on the surface of the Moon; extensively cratered, and chemically distinct from the *maria*.

Igneous: *Rocks* or processes involving the formation and solidification of hot, molten *magma*.

Ilmenite: Opaque mineral found in *basalt*; nearly pure iron-titanium oxide ($FeTiO_3$.)

Impact (see *Crater*): The forceful striking of one body, such as a *meteorite*, against another body such as a moon or planet.

Impactor (see *Projectile, Meteorite*): Object that impacts a surface.

KREEP: On the Moon, type of *highlands rock* rich in potassium (K), rare-earth elements (REE), and phosphorus (P).

Latitude: The angular distance North or South from the Earth's equator measured in degrees on the meridian of a point; Equator being 0° and the poles 90°N and 90°S.

Lava: fluid *magma* that flows onto the surface of a planet or moon; erupted from a *volcano* or *fissure*. Also, the *rock* formed by solidification of this material.

Levee: Zones in a *lava* flow where the lava between the zones is moving faster than the lava outside the zones.

Lifestyle (see *Sedentary*): A person's general pattern of living.

Longitude: The angular distance East or West, between the meridian of a particular place on Earth and that of Greenwich, England, expressed in degrees or time.

Lunar: Of or pertaining to the Moon.

Magma: Term applied to molten rock in the interior of a planet or moon. When it reaches the surface, magma is called *lava*.

Magma Ocean: Term used to describe the layer of *magma*, hundreds of kilometers thick; thought to have covered the Moon 4.5 billion years ago.

Magnetic field: The region of "altered space" that will interact with the magnetic properties of a magnet. It is located mainly between the opposite poles of a magnet or in the energetic space about an electric charge in motion.

Mantle: A mostly solid layer of Earth lying beneath the *crust* and above the *core*; consisting mostly of iron, magnesium, silicon, and oxygen.

Mare basalt: Rocks making up the dark, smooth, *mare* areas of the Moon

Mare "soil": *Sediment* on the surface of the *lunar maria*; fragments of *basalt rocks*, broken *mineral* grains, and glass produced by *impact*.

Maria (mare): Dark areas on the Moon covered by *basalt lava* flows.

Metamorphic: *Rocks* that have recrystallized in a solid state as a result of changes in temperature, pressure, and chemical environment.

Meteorite (see *Impactor, Projectile*): A metallic or stony (silicate) body that has fallen on Earth or the Moon from outer space.

Meteoritic bombardment: Intensive and prolonged *impacts* of a surface by *meteorites* or other *impactors*.

Mineral: Naturally occurring inorganic solid with a definite chemical composition and crystal structure.

Moonquake (see *Earthquake*)**:** Sudden motion or trembling of the Moon caused by the abrupt release of slowly accumulated elastic energy in *rocks*.

Mountain: A natural elevation of a planetary surface.

NASA: United States federal agency; National Aeronautics and Space Administration.

Nearside: The side of the Moon that always faces Earth.

Nondegradable (see *Biodegradable*)**:** Something that can not be chemically decomposed.

Norite: *Igneous* rock found in the *lunar highlands* composed of *plagioclase* and *pyroxene*.

Nuclear energy: Process by which the fission of ^{235}U releases heat to make steam, which then drives turbines to create electricity.

Nutrition: Process by which animals and plants take in and utilize food material.

Ocean of Storms: Landing site of *Apollo* 12 on the Moon on Nov. 19, 1969; Oceanus Procellarum.

Olivine: *Mineral* found in *basalt*; ranges from Mg_2SiO_4 to Fe_2SiO_4.

Orange "soil": On the Moon, a mixture of very small dark orange and black glass balls which formed from quickly cooled *lava* droplets during a *pyroclastic eruption*.

Organism: Any form of animal or plant life.

Pahoehoe: *Basaltic lava* with a smooth, billowy, or ropy surface.

Photosynthesis: The process by which plants convert water and carbon dioxide into carbohydrates, using sunlight as the source of energy and the aid of chlorophyll.

Plagioclase feldspar: Common *mineral*; ranges from $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$.

Plate tectonics: Theory formulated in the late 1960s that states the Earth's *crust* and upper *mantle* (a layer called the lithosphere) is broken into moving pieces called plates. The formation of *mountains* and *volcanoes*, and the occurrence of *earthquakes* have been explained using this theory.

Pressure ridges: Long, narrow wavelike folds in the surface of *lava* flows; formed where lava may have buckled up against slower moving or stationary lava downstream.

Projectile (see *Impactor, Meteorite*)**:** Object that *impacts* a surface.

Pyroclastic eruption: Explosive eruption of *lava* producing and ejecting hot fragments of rock and lava.

Ray: Streak of material blasted out and away from an *impact crater*.

Recycling: To treat or process waste materials making them suitable for reuse.

Regolith (see *Sediment, Soil*)**:** Loose, unconsolidated *rock*, *mineral*, and glass fragments. On the Moon, this debris is produced by *impacts* and blankets the surface.

Rille: Long *channel* on the Moon crossing the surface of *maria*; probably formed either as an open channel in a *lava* flow, or as an underground tube carrying hot lava which collapsed as the lava flowed out.

Robot: A machine that does mechanical tasks on command and operates automatically.

Rock: A naturally formed solid that is an aggregate of one or more *minerals*.

Scale: The relationship of a distance on a map or model to the true distance in space; written as a ratio, such as 1:24,000.

Sea of Serenity: One of the *maria* on the Moon's *nearside*; Mare Serenitatis.

Sea of Tranquillity: Landing site of *Apollo* 11 on the Moon on July 20, 1969; Mare Tranquillitatis.

Sedentary (see *Lifestyle*)**:** characterized by much sitting and little physical activity.

Sediment (see *Regolith*)**:** Soild *rock* or *mineral* fragments transported and deposited by wind, water, gravity, or ice; preciptitated by chemical reactions; or secreted by organisms; accummulated as layers in loose, unconsolidated form.

Glossary

Sedimentary: *Rock* formed when *sediment* is compacted and lithified.

Self-sustaining: Able to exist and function without outside help.

SNC meteorites (see *Meteorite*): Group of meteorites with relatively young ages (slightly over 1 billion years old) that probably came from Mars.

Soil (see *Regolith, Sediment*): The upper layers of sediment on Earth that support plant growth.

Solar power: Energy derived from the Sun or sunlight for use as a source of *electricity*.

Solar system: The Sun and all the objects (planets, moons, asteroids, and comets) that orbit the Sun.

Solar wind: The stream of charged particles (mainly ionized hydrogen) moving outward from the Sun with velocities in the range 300-500 kilometers per second.

Source (see *Eruption*): Location where *igneous* matter (*lava* and gases) erupts onto the surface; vent, *fissure*, *volcano*, etc.

Spacecraft: Vehicle capable of traveling in outer space.

Stratigraphy: Study of layered rock to understand the sequence of geological events.

Taurus-Littrow: Landing site of *Apollo* 17 on the Moon on Dec. 11, 1972.

Terrain: Area of the surface with a distinctive geological character.

Tool carrier: Storage container for tools on the *Apollo Lunar* Roving Vehicle.

Transportation: The means of carrying something from one place to another.

Troctolite: *Igneous* rock found in the *lunar highlands* composed of *plagioclase* and *olivine*.

Vesicle: Bubble-shaped cavity in a volcanic rock formed by expanding gases.

Volatiles: Chemical elements that enter a vapor phase at relatively low temperatures.

Volcano: *Mountain* formed from the eruption of *igneous* matter through a *source* vent.

Water conservation: The wise use of water as a natural resource; the prevention of loss or waste of water.

Weathering: The mechanical breakdown and chemical alteration of *rocks* and *minerals* at Earth's surface during exposure to air, moisture, and organic matter.

Zoologist: Scientist who studies animals.

(This Glossary was compiled by Meredith Lee, Hawai'i Space Grant College.)

NASA Spacelink: An Electronic Information System

NASA Spacelink is a computer information service that individuals may access to receive news about current NASA programs, activities, and other space-related information, historical data, current news, lesson plans, classroom activities, and even entire publications. Although it is primarily intended as a resource for teachers, the network is available to anyone with a personal computer and a modem.

Users need a computer, modem, communications software, and a long-distance telephone line to access Spacelink. The data word format is 8 bits, no parity, and 1 stop bit. The Spacelink computer access number is (205) 895-0028.

NASA Spacelink is also available through the Internet, a worldwide computer network connecting a large number of educational institutions and research facilities.
Internet address is 192.149.89.61

For more information, contact:

NASA Spacelink Administrator
Marshall Space Flight Center
Mail Code CA-21
Marshall Space Flight Center, AL 35812
Phone: (205) 544-6527

NASA Educational Satellite Videoconferences

During the school year, NASA delivers a series of educational programs by satellite to teachers across the country. The content of each videoconference varies, but all cover aeronautics or space science topics of interest to the educational community. The broadcasts are interactive: a number is flashed across the bottom of the screen, and viewers may call collect to ask questions or to take part in the discussion. For further information, contact:

Videoconference Coordinator
NASA Aerospace Education Services Program
300 North Cordell
Oklahoma State University
Stillwater, OK 74078-0422
Phone: (405) 744-7015

Technology and Evaluation Branch
Education Division
Code FET
NASA Headquarters
Washington, DC 20546-0001
Phone: (202) 358-1540

Teacher Resource Center Network

To make additional information available to the education community, NASA's Education Division has created the NASA Teacher Resource Center Network. Teacher Resource Centers (TRCs) contain a wealth of information for educators: publications, reference books, slides, audio cassettes, videocassettes, telelecture programs, computer programs, lesson plans and activities, and lists of publications available from government and nongovernment sources. Because each NASA Field Center has its own areas of expertise, no two TRCs are exactly alike. Phone calls are welcome if you are unable to visit the TRC that serves your geographic area. A list of centers and the geographic regions they serve appears on Pages 147 and 148.

To offer more educators access to NASA educational materials, NASA has formed partnerships with universities, museums, and other educational institutions to serve as Regional Teacher Resource Centers (RTRCs). For the location of the RTRC nearest you, please contact the TRC serving your geographic region.

NASA's Central Operation of Resources for Educators (CORE) was established as part of the Teacher Resource Center Network to facilitate the national and international distribution of NASA-produced educational materials in audiovisual format. Orders are processed for a small fee that includes the cost of the media. Send a written request on your school letterhead for a catalog and order forms. For more information, contact:

NASA CORE
Lorain County Joint Vocational School
15181 Route 58 South
Oberlin, OH 44074
Phone: (216) 774-1051, Ext. 293 or 294

General Information for Teachers and Students

If you live in:	Center Education Program Officer	Teacher Resource Center
Alaska Arizona California Hawaii Idaho Montana Nevada Oregon Utah Washington Wyoming	Chief, Educational Programs Branch Mail Stop 204-12 **NASA Ames Research Center** Moffett Field, CA 94035-1000 PHONE: (415)604-5543	NASA Teacher Resource Center Mail Stop T12-A **NASA Ames Research Center** Moffett Field, CA 94035-1000 PHONE: (415)604-3574
Connecticut Delaware Dist. of Columbia Maine Maryland Massachusetts New Hampshire New Jersey New York Pennsylvania Rhode Island Vermont	Chief, Educational Programs Mail Code (130) **NASA Goddard Space Flight Center** Greenbelt, MD 20771-0001 PHONE: (301)286-7206	NASA Teacher Resource Laboratory Mail Code 130.3 **NASA Goddard Space Flight Center** Greenbelt, MD 20771-0001 PHONE: (301) 286-8570
Colorado Kansas Nebraska *New Mexico* North Dakota Oklahoma South Dakota *Texas*	Center Education Program Officer Education and Public Services Branch (AP-4) ***NASA Johnson Space Center*** *Houston, TX 77058-3696* *PHONE: (713)483-1257*	NASA Teacher Resource Center Mail Code AP-4 ***NASA Johnson Space Center*** *Houston, TX 77058-3696* *PHONE: (713) 483-8696*
Florida *Georgia* *Puerto Rico* *Virgin Islands*	*Chief, Education Services Branch* *Mail Code PA-ESB* ***NASA Kennedy Space Center*** *Kennedy Space Center, FL 32899-0001* *PHONE: (407)867-4444*	*NASA Educators Resource Laboratory* *Mail Code ERL* ***NASA Kennedy Space Center*** *Kennedy Space Center, FL 32899-0001* *PHONE: (407) 867-4090*
Kentucky North Carolina South Carolina Virginia West Virginia	Center Education Program Officer Office of Education Programs, Mail Stop 400 **NASA Langley Research Center** Hampton, VA 23681-0001 PHONE: (804) 864-8102	NASA Teacher Resource Center ***Virginia Air and Space Center*** 600 Settler's Landing Road Hampton, VA 23669-4033 PHONE: (804) 727-0900 x757

If you live in:		Center Education Program Officer	Teacher Resource Center
Illinois Indiana Michigan	Minnesota Ohio Wisconsin	Acting Chief, Office of Educational Programs Mail Stop 7-4 **NASA Lewis Research Center** 21000 Brookpark Road Cleveland, OH 44135-3191 PHONE: (216)433-2957	NASA Teacher Resource Center Mail Stop 8-1 **NASA Lewis Research Center** 21000 Brookpark Road Cleveland, OH 44135-3191 PHONE: (216)433-2017
Alabama Arkansas Iowa	Louisiana Missouri Tennessee	Director, Executive Staff Code DX01 **NASA Marshall Space Flight Center** Marshall Space Flight Center, AL 35812-0001 PHONE: (205) 544-8843	NASA Teacher Resource Center **U.S. Space and Rocket Center** Huntsville, AL 35807-7015 PHONE: (205)544-5812
Mississippi		Manager, Educational Programs Mail Stop MA00 **NASA John C. Stennis Space Center** Stennis Space Center, MS 39529-6000 PHONE: (601)688-1107	NASA Teacher Resource Center Building 1200 **NASA John C. Stennis Space Center** Stennis Space Center, MS 39529-6000 PHONE: (601) 688-3338
The Jet Propulsion Laboratory (JPL) serves inquires from all over the nation related to space and planetary exploration and other JPL activities.		*Manager, Educational Affairs Office* *Mail Code 183-900* ***Jet Propulsion Laboratory*** *4800 Oak Grove Drive* *Pasadena, CA 91109-8099* *PHONE: (818) 354-8251*	*NASA Teacher Resource Center* *JPL Educational Outreach* *Mail Code CS-530* ***Jet Propulsion Laboratory*** *4800 Oak Grove Drive* *Pasadena, CA 91109-8099* *PHONE: (818)354-6916*
California (mainly cities near Dryden Flight Research Facility)			*Public Affairs Office (Trl. 42)* *NASA Teacher Resource Center* ***Dryden Flight Research Facility*** *Edwards, CA 93523-0273* *PHONE: (805)258-3456*
Virginia and Maryland's Eastern Shores			Education Complex-Visitor Center Building J-17 **Wallops Flight Facility** Wallops Island, VA 23337-5099 PHONE: (804)824-2297/2298

Educators and scientists at the National Aeronautics and Space Administration would appreciate your taking a few minutes to respond to the statements and questions below. Please return by mail.

SA - Strongly Agree
A - Agree
D - Disagree
SD - Strongly Disagree

Exploring the Moon - *Activities for Earth and Space Science*

1. The teaching guide is easily integrated into the curriculum.	SA	A	D	SD
2. The procedures for the activities have sufficient information and are easily understood.	SA	A	D	SD
3. The illustrations are adequate to explain the procedures and concepts.	SA	A	D	SD
4. Activities effectively demonstrate concepts and are appropriate for the grade level I teach.	SA	A	D	SD

5. a. What features of the guide are particularly helpful in your teaching?

____

b. What changes would make the guide more effective for you?

____

6. I teach _____ grade. Subjects ______________________________

7. I used the guide with _____ (number of) students.

Additional comments: ______________________________

____

____

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